Elements of natural philosophy

Golding Bird

ELEMENTS

OF

NATURAL PHILOSOPHY;

BEING AN

EXPERIMENTAL INTRODUCTION

TO THE

STUDY OF THE PHYSICAL SCIENCES.

BY

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WITH THREE HUNDRED AND SEVENTY-TWO ILLUSTRATIONS.

FROM THE REVISED AND ENLARGED THIRD LONDON EDITION.

PROSUNT QUAE OMNIBUS.

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"Quicquid enim ex phenomenis non deducitur, hypothesis vocanda est; et hypotheses seu metaphysicæ, seu physicæ, seu qualitatum occultarum, seu mechanicæ, in philosophia experimentali, locum non habent. *In hac philosophia propositiones deducuntur ex phenomenis, et redduntur generales per inductionem.*"

NEWTON, PRINCIP. MATHL. PHIL., lib. iii., Schol. Gen.

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PREFACE

TO THE THIRD EDITION.

Being again called upon to prepare a new edition of this work, I have anxiously endeavored to render it as complete as possible, and worthy, in some degree, of that patronage with which it has been previously honored. I hope that none of the rich contributions to experimental physical science, which have been made public since the last edition, have been overlooked. In making these necessary alterations and additions, it has been my earnest desire, never to lose sight of the humble and limited design of this work, and which, indeed, first induced me to offer it to public notice.

Myddelton Square,
Dec. 1847.

PREFACE

TO THE FIRST EDITION.

The best apology that can be offered for presenting this volume to public notice, will be found in the reason which suggested its compilation, viz., the absence of any system of physics, sufficiently extended to include all those subjects with which men of education, especially members of a liberal and important profession like that of medicine, ought, and are required, to be familiar with; and at the same time, not too diffuse to disgust or weary the student.

To the student of medicine, and chemistry in particular, the want of a concise, and yet sufficiently comprehensive work on physics has been long felt; as, without an acquaintance with the physical sciences, his professional education must be considered as far from complete; and, independently of this, a knowledge of the principles of these sciences has long been rendered imperative at the different medical boards, and has constituted an important part of the examination which the candidate for a diploma is called upon to undergo.

The following manual is chiefly intended as a text-book for the student, whilst attending lectures on physics, or as preparatory to his entering upon the study of larger and more elaborate works. With this view it has been written; and as the great difficulty experienced in executing this task has arisen from the necessity of knowing, not what to insert, but what to omit, whenever a

doubt has arisen on this point, it has been determined by a reference to the amount of knowledge required of the student, by the different English and Scottish medical boards.

A work of this kind I had long ago projected, in consequence of not being acquainted with any in the English language, to which I could refer the students attending the lectures on physics, annually delivered at Guy's Hospital; although I had hitherto shrunk from the task, hoping that a production, so much required by the medical and general student, would have emanated from some more able writer.

As an apology for the arrangement followed in this volume, it must be observed, that utility and extreme simplicity, rather than elegance of style, were sought for, and every other object has been sacrificed to obtain this end. The division into numbered paragraphs was adopted, as every chapter would thus become a kind of running commentary on the others, and would, moreover, facilitate reference to distinct subjects in the Analytical Index.

I regret, as every writer on so extensive a series of subjects must do, the impossibility of doing justice to every laborer in the field of philosophic inquiry, by referring each discovery to its author; as far as this could, without circumlocution, be effected, it has been done. For discoveries of longer date, as they have become the common property of science, there needs no apology for not, in every case, mentioning the name of their authors in a strictly elementary work.

I have been greatly indebted to several writers in the French and German languages, for many suggestions and illustrations, of which I have never hesitated to avail myself, whenever they appeared to divest any subject of obscurity, or to add to its interest. To the "Précis de Physique" of Biot, the "Elémens de Physique" of Pouillet, the "Traité de Physique" of Hauy, the "Positions de Physique" of Quetelet, and the "Grundriss der Experimental-Physik" of Kastner, I have been peculiarly indebted for several illustrations, some of which have not, I believe, previously appeared in an English dress.

Having thus explained the object and unpretending character of this volume, I trust enough has been said to blunt the edge of

criticism, should such, perchance, be levelled against it. The critic himself, I would beg to remind of the celebrated observation of Horace:—

> "Sunt delicta quibus nos ignovisse velimus,
> Nam neque chorda sonum reddit quam vult manus et mens;
> Nec semper feriet quodcunque minabitur arcus."

Those readers who desire further information on the subjects treated of in this work, and have not the assistance derived from attendance on lectures, may, if only a popular acquaintance with them be required, refer to the very elegant, although yet unfinished, "Elements of Physic" of Dr. Arnott, or to Sir David Brewster's edition of "Euler's Letters to a German Princess." Those who require a more profound acquaintance with these important subjects, should consult the books referred to in the body of this volume, as well as to the treatises published by the Society for the Diffusion of Useful Knowledge. The series of Essays written by the professors of King's College, London, now in the course of publication, will also furnish most valuable comments on this, and other elementary works.

In the execution of this task, I have experienced but one source of regret, and one which every person engaged in the duties of a laborious profession must feel, when called upon to write on a series of subjects, to a certain extent distinct from his immediate duties, and requiring, for their elucidation, a much greater amount of time, than his more onerous engagements will allow him to devote to them;—a source of regret arises from the feeling, that a work of this kind had not appeared from the pen of one better fitted to the task, than of him who now offers it to public notice.

October, 1839.

PREFACE

TO THE SECOND EDITION.

In this edition I have endeavored to make such improvements as shall render it worthy of the patronage bestowed upon the first, which has been for some time out of print.

The principal additions made to this work consist in the introduction of three chapters, embracing the subjects of thermotics, and the chemical action of light. The chapters on electro-chemical decomposition, and part of those on polarized light, have been re-written. I have endeavored to elucidate, as much as possible, whatever appeared obscure, so as to facilitate the labors of the student. To assist which, about eighty new wood-cuts have been added.

Myddelton Square,
Nov. 1843.

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INTRODUCTORY DISCOURSE.

The natural phenomena which are incessantly developing themselves on our earth, and in the vast space around us, offer to our view so magnificent a spectacle, that the curiosity of the most listless observer becomes powerfully aroused, and in spite of himself he is compelled, in a greater or less degree, to meditate upon the causes capable of producing such marvellous effects. Scarcely is man emancipated from the trammels which confine the reasoning powers during lisping infancy, ere his childish attention becomes attracted by the objects so lavishly scattered around him by the bounteous hand of nature; he observes with all the energy of his young mind the brilliant constellations bespangling the firmament, and the dim outline of the distant landscape, whilst the less striking, but to him equally important, the abstract properties of matter, force themselves on his maturer understanding: the weight of all surrounding bodies—the rippling of the village brook, or roaring of the torrent—the summer's breeze, or wintry hurricane—alike attract his notice; and, from the brilliant vault of heaven to the surface of his own terraqueous habitation, he culls food for meditation, and finds everywhere infinite sources of wonder and delight. But, in the midst of the vast range of natural effects, it is not given to his intellectual faculties to acquire at once a knowledge of the causes producing them, nor to grasp by one bold effort of the mind, a comprehension of the laws which these phenomena obey. By slow degrees has this knowledge been acquired; and even now, notwithstanding the number of zealous and devoted laborers in the field of natural science—notwithstanding the accumulated experience of ages, is this knowledge, on many and very important points, deficient. This, however, so far from daunting the student at the outset of his career, should hold out a great attraction for him; urging his exertions in the cause of science, by the prospect it extends of reward in the achievement of some grand discovery; which may, perchance, place *his* in that bright galaxy of names which has adorned science, and be transmitted to an admiring posterity by the side of a Bacon, a Franklin, a Herschel, or a Davy.

Few things are more interesting than to trace the history of the development of the efforts of the human mind, from the earliest dawn of infant science in the records of past times, through the depressing gloom of the lurid and superstitious era of the dark ages, when science was denounced as a crime, and a Bacon, and a Galileo, for being its successful cultivators, subjected to the thraldom of the Inquisition, up to our own brighter and happier days, in which philosophy and the allied branches of knowledge are recognized as objects of the first importance, the man of science respected, and his acquirements appreciated. What singular and diversified opinions do we not meet with upon record concerning the properties of bodies and their component elements; upon

the principles and forces which act on inert matter, and maintain the harmony of the universe. What mazes of hypothesis and errors shall we not find!—what a deep mist of confusion!—in the midst of which are scattered a few truths, the offsprings of earlier talents, like stars, rendering more intense by contrast the darkness of the veil of ignorance and error, obscuring what little was known of nature's laws. Well has it been said, by a talented writer of the present day, that it is "a condition of our race, that we must ever wade through error in our advance towards truth; and it may even be said, that in many cases we exhaust every variety of error before we attain the desired goal. But truths reached by such a course are always most highly to be valued; and when, in addition to this, they may have been exposed to every variety of attack, which splendid talents, quickened into energy by the keen perception of personal interests, can suggest; when they have revived undying from the gloom of unmerited neglect; when the anathema of spiritual, and the arm of secular power have been found as impotent in suppressing, as their arguments were in refuting them—then they are indeed irresistible. Thus tried, and thus triumphant, in the fiercest warfare of intellectual strife, even the temporary interests and furious passions which urged on the contest have contributed in no small measure to establish their value, and thus to render these truths the permanent heritage of our race. Viewed in this light, the propagation of error, although it may be unfavorable or fatal to the temporary interests of an individual, can never be long injurious to the cause of truth. It may, at a particular time, retard its progress for a while, but it repays the transitory injury by a benefit as permanent as the duration of the truth to which it is opposed!"*

Under the general term of Natural Philosophy is comprehended so vast a range of inquiry, that some division of labor becomes necessary not only for the teacher, but the student. Some of the sciences included under this title are so absolutely necessary to the ordinary duties of civilized life, that they form an important part of early education. The properties of numbers, including ordinary, logarithmic, and algebraic arithmetic, a general outline of the arrangements of the universe, comprehending astronomy and geography, with mathematics and geometry, fall under this head, and now constitute a part of the acquirements of every well-educated member of society. Divested of these sciences, Natural Philosophy may be divided, 1st, into the knowledge of the arrangements of the strata composing our globe, and of the remains of the extinct and wonderful inhabitants of the primeval world, forming the sciences of geology and physical geography; 2dly, into the study of the effects resulting from the action of atoms of different forms of matter upon each other, constituting the splendid and comprehensive science of chemistry; and 3dly, into an investigation of the constitution of masses of matter, the laws governing them, and the mutual action of different atoms of the *same* kind; with an examination of the relation they bear to space, and to the various members of the universe, comprehending the study of physics.†

The latter vast and beautiful range of inquiry is that which we are now to commence the investigation of, whose laws we are to study, and whose effects we must endeavor to appreciate. It is scarcely necessary to state, that a general acquaintance with the principles of this portion of natural knowledge, is indispensable to every one whose duties or inclination induce him to investigate any of the phenomena connected with the organic or inorganic world, or that a correct acquaintance with even the rudiments of chemistry cannot be obtained without them; the effects of chemical affinity and electric

* Babbage, Bridgewater Treatise, p. 28.
† φύσις, natura.

action being so connected, that, in the opinion of one of the most eminent philosophers and successful cultivators of science of the present day, they depend upon one and the same cause for their production and effects.

Complex and obscure as the laws of the material universe may appear to the superficial observer, surrounded by difficulties and lost in the maze of phenomena around him, he might be tempted, like the philosophers of old, to refer every effect to its own peculiar cause; a cause innate to the substance, essential to it, and animating like a soul. Far otherwise are the conclusions arrived at by him who, patiently investigating the appearances of the material world, is guided by the inductive reasoning of the Baconian school: *he* traces effects to their proximate causes, and generalizing these, is led to the discovery of a few simple laws, obeying which, atom unites to atom, and mass to mass, to form a world, rolling in its appointed sphere around the centre of our system, the great source of light and heat;—*he* soon discovers that, in the beautiful simplicity of Nature's laws, the apparently most insignificant, and the most gigantic effects are frequently produced by one and the same cause; *he* discovers that the very law which presides over the motions of the luminous orbs which roll in space around him, causes the scattering of flour from the edge of the mill-stones, and of drops of water from the wet revolving carriage-wheel. That the law regulating the falling of an apple towards the earth, is identical with that which retains the mountains on their broad bases and the planets in their spheres. Nay, more, he learns that with such consummate wisdom have cause and effect been related, that the very same power is often sufficient to produce effects apparently totally opposed. Thus, the force by which the ocean is retained in its bed is the same as that by which the ships float upon its surface; the law which regulates the velocity of a falling avalanche, is identical with that by which the balloon ascends in the air—and the power by which the torrents in the falls of Niagara acquire their terrific velocity, is the same which has retained unmoved for ages, the solid rocks from which they descend.

Experience and observation constitute the true guides for the investigations of the philosopher; and, aided by the soundest inductive reasoning, they, in the hands of the immortal author of the Principia, developed those great truths which astonished the world, and whose light ultimately dispelled the last traces of obscurity with which the Aristotelian and Cartesian systems continued to encumber philosophy. The celebrated *Reguli Philosophandi* left us by Newton cannot be too deeply impressed upon the mind of the student, and should be confided in as the best guides in reasoning from experiment.

RULE I.

We are to admit no more causes of natural things than such as are both true and sufficient to explain their appearances.

RULE II.

Therefore, to the same natural effects we must, as far as possible, assign the same causes.

RULE III.

The qualities of bodies, which admit neither intension nor remission of degrees, and which are found to belong to all bodies within the reach of our experiments, are to be esteemed the universal qualities of all bodies whatsoever.

RULE IV.

In experimental philosophy, we are to look upon propositions collected by

general induction from phenomena as accurately, or very nearly true, notwithstanding any contrary hypothesis that may be imagined, till such time as other phenomena occur, by which they may either be made more accurate, or liable to exceptions.*

Before we can satisfactorily proceed to an investigation of the laws governing matter, in the masses in which it is presented to our senses, it is obvious that something approaching to a succinct and tolerably clear view of the internal composition of each individual material mass should be obtained. By the physical composition of a mass of a material substance, we by no means refer to its chemical constitution; we do not inquire which or how many of those substances, which chemists at present consider as primary or simple, are present; we refer solely to the physical structure of the mass. Thus, for example, in a ball of marble, which is known to consist of carbon, oxygen, and calcium, it is not inquired how much of these respective ingredients are present, but *in what manner* the minutest physical atom of the compound (chemically speaking) substance, marble, is held in connection or relation to that next to it.

It would be useless to occupy time by recapitulating all the theories that have been proposed for the resolution of this question from the time of Leucippus, Democritus, and the great philosopher of Stagyra, to our own era. Beautiful and ingenious as many of these hypotheses are, they often fail to bear the rigid investigation of truth, and too frequently are found to have their superstructure based on no better foundation than that of the brilliant and fertile imagination of those who introduced them to the world.

If we take a mass of any form of matter, and reduce it to the finest impalpable powder by any mechanical means, it must not be considered that this state of comminution, however fine and minute, has put us in possession of atoms of matter in their minutest state of division; for, on examining with a lens a particle of the powder thus obtained, we find it closely resembles in its physical characters the mass from which we obtained it, and of which it may be regarded as a miniature likeness. So that it is probable that, had we cutting instruments sufficiently delicate, and visual organs sufficiently microscopic, we might continue dividing this particle into numerous smaller portions. This circumstance has been very lately proved, by the microscopic labors of Ehrenberg, to be strictly and literally correct, and to hold good where it was least expected. This philosopher, among other observations, has shown that carbonate of lime, in its minutest state of comminution, after it has been exposed to the action of a mill, and then the finest portions separated by the operation of elutriation, still under a good microscope appears to be composed of transparent rhomboids, with angles as perfect as in the finest specimens of calcareous spar. Here arises the first question in this stage of our inquiry; for, admitting that we are able to continue our division of the particles, we should naturally ask, what would be its limit?—could it be carried on to infinity, or is there a point at which it must stop? There are some philosophers who consider that this state of division may be carried on to infinity, and, consequently, that matter is divisible forever. If this be the case, there can be no such thing as an atom; certainly not, if its strict definition be adhered to. What, then, can a mass of matter be constructed of? Can it be supposed to consist of an aggregation of infinitely divisible particles? If so, of what are these particles themselves composed, if their division can be continued forever? So that we are almost compelled to regard the division of matter as limited: for, if we do not admit this finite division of masses, we can have no idea, or capability of appreciating its compound particles. To appreciate

* Princip. Math. Philos., lib. iii.

numbers, we must be acquainted with the number of units they contain; to appreciate a mass, we must admit the existence of a finite division into particles or atoms. Again, no one can suppose matter to be else than mortal; it is no attribute of spiritual or immortal beings; then, if we admit that matter is essentially connected with beings which are limited in duration or existence, does it not appear to involve an absurdity to suppose that the constituents of that which is limited in existence are infinite in number? "It would be as easy to believe that a moment of time may be lengthened into an infinity of ages, as to suppose that matter is infinitely divisible. Nothing can be more revolting to reason than eternal time; infinite divisibility is not less absurd;" although it must be acknowledged a most difficult task to adduce a precise refutation of all the mathematical sophistry and subtleties concerning infinite divisibility, with which the question has been loaded. The mind is unable to continue the contemplation of this subject; it becomes bewildered in the mazes of the question, and seeks relief from the obscurity enveloping the labyrinths which the thinking powers are unable to penetrate, in the consideration of deductions countenanced by reasoning, experiment, and observation.

We have next to inquire, by what force the particles of matter, which we have obtained by the mechanical comminution of a mass, were held together previous to their forcible separation. Some force must exist for this purpose, otherwise no such thing as an aggregation of atoms forming a mass could ensue; for we can consider particles of dead matter only as absolutely inert, and, therefore, of themselves could not oppose that obstacle to their forcible separation which is presented by every solid material mass; and this reasoning brings us to notice a most energetic force presiding over the internal constitution of bodies. This force is *attraction;* and constitutes the unseen band by whose aid one particle of matter is held in close approximation to a second, and thus causes the formation of a mass. Reasoning from known facts, teaches us that this attractive force must be considerable, otherwise it would be impossible to account for the difficulty we experience in attempting to divide a mass of any substance; it also teaches us that its sphere of action is limited to distances quite insensible to the eye, even when assisted by the best microscopes. For, having once reduced a mass to powder, the minute particles composing it ought again to unite on collecting them into a heap on a piece of paper; for they appear to the naked eye to touch each other, and therefore to afford every opportunity for the exertion of a mutual attractive force to reconstruct the mass we have disintegrated. But we know that this attraction does not become apparent; the particles of matter do not fly together, unite, and form a mass; therefore, it must follow that the sphere or extent of molecular attractive force is extremely limited.

The attraction between two particles cannot be *infinite*, for if so, no earthly power could effect their separation; hence there must exist some power or force modifying this attraction, acting consequently in opposition to it. For it appears evident from the results of experiment that, although two particles have so powerful an attraction for one another, as soon as they are brought within the sphere of each other's attraction, that they unite and constitute one mass; yet, that if it be attempted to bring them into absolute contact, a most powerful resistance is opposed to our attempts, and the task becomes impracticable, demonstrating the existence of a repulsive force between individual particles as well as between masses of matter. Admitting the existence of these two forces, attraction and repulsion, acting on the particles of matter, let us investigate the attributes of the latter in its minutest physical state of division, rejecting entirely the hypotheses I have hinted at, which consider matter either as infinitely divisible or as entirely non existent: for theories of

this kind must be regarded as purely metaphysical, and therefore quite distinct from our present investigations. Indeed, by reasoning on matter in the abstract, we gain comparatively little: it is by studying it in relation to other masses, and the external world, that we gain any practically useful information.

It has been fairly deduced from accurate reasoning and observation, that all ultimate physical, indivisible atoms, possess the attributes of impenetrability, hardness, and figure. What their form really is, it is impossible to say; philosophers have exhausted the fertility of their imaginations on this subject. The ancients supposed them to be possessed of various forms; most modern writers have assumed them to be spherical; and, certainly, in reasoning on their properties and attributes, this form is found most available; a late Italian author has attempted to prove them to be pyramidal. To enter into these speculations would, however, be useless and unprofitable, as it is self-evident that no direct proof can be brought to bear upon the subject. If the component atoms of any form of matter be placed sufficiently near to each other, by the action of a mutually attractive force, we have a *solid* produced; if a repulsive energy be then exerted, the atoms fly asunder, and we have a *soft solid*, or *liquid;* and this, upon a still farther application of repulsion, becomes converted into a *gas*, or *vapor*, from the more distant separation of its component atoms. As an example of these different states, let us take ice. This is a well known solid of considerable hardness, justifying the idea that its atoms are very closely approximated to each other; on applying a gentle heat, these atoms separate, and a fluid, water, is produced; a still greater degree of heat causes a further separation of atoms, and a vapor, steam, is generated: in this state a given number of atoms occupy a space more than seventeen hundred times greater than they did when constituting fluid water. Many other forms of matter may be made to assume the several states of *solid*, *fluid*, and *gas*. In the case of carbonic acid, this is beautifully demonstrated, an invisible gas having, under powerful pressure, its molecules so approximated that a fluid is formed; and then, under the influence of intense cold, a still further approximation ensues, and a white solid, resembling snow, is produced. All these several states of matter will fall under our observation in the investigation of the sciences of Statics, Dynamics, Hydrostatics, and Pneumatics. (Chap. I.—VIII.)

Masses of matter constituted in the manner thus described are said to be *brittle*, if the attraction between their atoms is so weak as to be overcome by a slight blow;—to be *tenacious*, if this attraction is so intense that it cannot be readily overcome;—and to be *elastic*, if, upon the application of force, their atoms allow of partial separation, and rapidly reunite on the removal of pressure. If, for example, a glass vessel be lightly struck, its atoms momentarily separate, then rapidly return to their normal state, and by a series of isochronous oscillations, their movements are communicated to the air, an eminently elastic body: alternate dilatations and contractions ensue in those layers of air nearest the agitated body; these become gradually extended into the great mass of atmosphere, like the waves formed on the surface of a lake by the falling in of drops of rain, and gradually extend in rapidly dilating circles until they vanish from the eye of the observer. When these vibratory movements occur with sufficient rapidity, they excite in the organs of hearing that sensation termed a *sound*, and on the quickness or slowness of their succession depend all the varieties of grave and shrill tones. Less than sixteen vibrations in the second are imperceptible as a continuous sound to the most delicate ear, whilst the greatest number perceptible in that time are probably much less than nine thousand, producing an exceedingly sharp sound, or rather shriek. An examination of these effects belongs to the science of *Acoustics* or *Sound*. (Chap. IX.)

Having assumed that all matter is made up of material, minute, indestructible, spherical atoms, we see at a glance that, let the attracting force emanating from their centres be ever so intense, interspaces *must* exist. Now, as to the state of these interspaces, more discrepancy of opinion has existed than on any other point of philosophic inquiry; some supposing them to be empty, others filled with an ethereal matter. Here Descartes found his vortices; and here the more ancient philosophers located their ether, animating the mass, and enduing it with its peculiar properties. The latter opinion, although exploded for ages, is probably, with some modification, very near the truth; all reasoning and all experiment tending to the belief that these interspaces are filled with an imponderable form of matter, playing a most important part in the phenomena of the material world. Such, indeed, appears to have been the opinion of Sir Isaac Newton, who refers, in the queries appended to his Optics,* to some of the probable properties and effects of this subtle and imponderable form of matter. His almost superhuman mind even grappled with the difficult question of the probable density and elasticity of this medium, as compared to air. Although possessing but slender data for investigation, derived chiefly from the rapidity of propagation of sound, as compared with that of light deduced from the horizontal parallax of the sun, Newton has shown that imponderable ether must be at least 700,000 times less dense than air; and that its elastic force, as compared to its density, must be, at the lowest estimate, 490,000,000,000 times greater than that of air. It is obvious that this imponderable form of matter, or ether, which we have assumed to occupy the interspaces existing between the solid particles of ponderable matter, is not limited to these localities, but independent of occupying what would otherwise be vacua between the gaseous atoms of our atmosphere, even in its most attenuated state, extends beyond its confines, as well as those of all the ponderable elements of our globe, into space;—here forming an invisible and imponderable fluid ocean, in which the vast orbs of our universe roll on unimpeded in their majestic courses.

It has been objected to this view of the presence of imponderable matter beyond the limits of our own world, that it has no further foundation for its existence than the necessity of its presence to support the undulatory hypotheses of light and heat. And it has been stated, that, were space actually full of this matter, we should expect a certain amount of retardation in the velocity of the planets of our universe. But when the extreme tenuity of ether is considered—when it is recollected, that, in comparsion with the air we breathe, it is at least three hundred times lighter than the latter is when compared with the density of a granite rock, no considerable amount of influence on the movements of the members of our universe can be reasonably expected. Still, that it does exert an influence is now indisputable, as it has been demonstrated by Encke, in the revolution of the comet which bears his name, that an acceleration of two days occurs at each revolution. That this acceleration of a body which possesses probably no more solidity than a wreath of vapor, is the actual result of a retarding influence, may appear at first sight paradoxical, but a moment's reflection will remove all doubt upon the matter. The planets and comets, whilst revolving in paths more or less eccentric around the sun, move with such velocity as to generate a powerful centrifugal or centre-flying force, which prevents their obeying exclusively the attractive power of the sun. So long as these two forces are equally balanced, no alteration in the revolutions of a comet or planet can occur; but any variation in the intensity of ether will exert a powerful influence upon these wandering bodies. The existence of a resisting medium tends to retard

* Optice, sive de reflexionibus, &c., lucis, lib. iii., Qu. 18-24. London, 1719.

the velocity of a moving body, and hence diminishes its centrifugal force. The result of this diminution is, that the comet obeys the attraction of the sun, and completes its orbit in a smaller ellipse than it did before such an influence was exerted; it consequently attains its apparent place in the heavens earlier at each revolution, so as to perform each in an orbit nearer to the sun. As Encke's comet completes its revolutions in about 1,208 days, and loses less than one-thousandth part of its velocity at each revolution, it will require 7,000 revolutions, or about 23,000 years, for it to move with one half its present velocity. Another comet, known as Biela's, which completes its orbit in 6¾ years, attained its apparent place in the heavens at its last revolution one day earlier than it would have done if no retarding medium existed. These facts weaken the force of one of the most plausible objections against the hypothesis of the existence of ether in space.

One of the most mysterious and wonderful properties of imponderable matter, is the power it possesses, under certain circumstances, of effecting an alteration in the particles of ponderable and even solid bodies. It is now certain that a sunbeam cannot fall upon a body without its exerting some important physical or chemical change, and that every alternation of light and shade which occurs produces a more or less permanent effect on the surface which receives them. What can be more evanescent even to a proverb, than a shadow, whether we regard it in its commonest sense, or as applied to the beautiful colored images of the camera obscura, or the startling spectral illusions of a concave mirror? Yet the natural magic of modern science has taught us how to make even these permanent; and by the art of photography (Chap. XXX.) has enabled us to

"Catch the fleeting shadow as it flies,"

and has thus given us the power of compelling a landscape to paint its own picture.

There is this remarkable apparent difference between ponderable and imponderable matter, that, whilst to cause the former to assume motion, absolute contact with another ponderable mass is required, the latter assumes that state without visible contact, and even at considerable distances from the moving power. This may, however, be, after all, only an apparent difference, absolute contact of ethereal atoms through the medium of the atmosphere in all probability occurring, although not obvious to us on account of the invisible nature of the agent whose effects we are examining. Thus, a bar of iron, whose imponderable interstitial atoms have been, by a process elsewhere described, arranged in such a manner as to present the phenomena of magnetism (Chap. X.), may be placed upon a pivot, and yet assume no motion without contact of the hand; on approaching it, however, by a second mass of iron, whose ethereal atoms have been similarly arranged, the suspended bar moves long before contact of the two bars occurs. And the recent labors of our great countryman, Dr. Faraday, have shown that this magnetism possesses a far higher interest to us, its dominion not being acknowleged merely by bars of iron, but being obeyed by almost every form of matter. Imponderable ethereal matter may be occasionally elicited in a state accompanied by luminous phenomena, as, on turning the plate of an electric machine, vivid flashes of light rush to the hand held near the apparatus; presenting us with mimic lightning of the same nature, and similating in its effects that which awes us when exhibited on the large scale in the theatre of nature. These effects we shall study when investigating the science of electricity. (Chap. XI.) One of the most remarkable properties of this form of imponderable matter is the power it appears to possess of rushing through dense metallic wires like water through open tubes; this, and its invisibility, caused it to be ranked

among the most mysterious agents; and its almost miraculous effects would, had they been known in the middle ages, have placed, as a knowledge of magnetism in one instance really did, its cultivators in danger of the stake at the hands of inquisitorial ignorance, for a supposed connivance with the powers of darkness.

The subtle and invisible forms of ethereal matter, when caused to assume a vibratory or undulatory movement with sufficient rapidity, produce a peculiar set of phenomena, whose effects are known by the terms of light and heat; effects of vast importance, for without them nature would be dead to us, its beauties no longer apparent, and this world a cheerless waste. The vibrations of ethereal matter required for the production of the perception of colors are inconceivably rapid, no less than 458 millions of millions in a second of time, being required to communicate to the retina the sensation of scarlet, and 727 millions of millions in the same space of time to communicate that of violet; and to appreciate these rapid undulations has the delicate mechanism of the eye been arranged by an All-wise Creator. The consideration of these phenomena is the province of the science of Optics (Chap. XXI.) and Thermotics (Chap. XXVIII.).

In the foregoing observations, I have thus given a view of the constitution of masses of matter, sufficiently extended to enable the student to commence an investigation of their properties, and have pointed out to him those beautiful and important branches of science, to the elementary investigation of which, these pages are devoted.

To this no less interesting, than important and attractive, series of investigations, the attention of the student is now invited, fully confident that all the difficulties that may at first appear in his course, will disappear by a very little exertion of patience and attention, and that, instead of proving stumbling-blocks, they will furnish so many stimuli to exertion. He will ultimately reap a rich reward for his labor, by finding his knowledge of Nature's works and laws improved, and to a certain extent, it is hoped, perfected; whilst the professional student will, in his own peculiar department, find that his knowledge of the action of the heart and circulating system will be improved by an acquaintance with the laws of fluid motion; that his knowledge of the physiology of the respiratory functions will not be diminished by an acquaintance with the laws of atmospheric pressure; that his ideas of the physiology of muscular action will be extended, by being able to explain it on mechanical principles; and that his knowledge of some of the vital functions will be increased and facilitated by the study of electric currents.

These are but a few of the attractions which a study of physics holds out. I might also refer to the connection of the physical sciences with the ordinary duties of life, and allude to their infinite importance in affording the key to a vast series of natural phenomena, as well as to the sources of gratification experienced from an acquaintance with the laws governing the hurricane, the torrent, and the tempest; by which these otherwise terrific agents become divested of half their terrors, by our being able to remove those with which popular superstition and ignorance have surrounded them.

These are some of the rewards which extend to those who pay even a slight attention to the physical sciences. They are raised above their fellow men by their increase of knowledge, knowledge of the most valuable kind, applicable, in a greater or less degree, to their different professions, and to all the resources of civilized life; whilst, from gazing on his beauteous works, and admiring the harmony and simplicity of the laws He has impressed on nature, they are compelled to regard with no less gratitude than admiration their divine Author, and become enabled to appreciate the full force of the

sublime and beautiful remark of one of the most celebrated philosophers* of ancient Greece, who, more than twenty-two centuries ago, notwithstanding his necessarily very limited acquaintance with the laws governing the universe, declared that—

"The world is God's epistle to mankind."

We are also taught how we may more "nearly behold the beauties of nature, and entertain ourselves with their delightful contemplation; and, which is the best and most valuable part of philosophy, be thence excited the more profoundly to reverence and adore the great Maker and Lord of all. He must be blind who, from the most wise and beautiful contrivances of things, cannot see the infinite wisdom and goodness of their Almighty Creator; and he must be mad or senseless who refuses to acknowledge them."†

* Plato.
† Cote's Preface to the Second Edition of the Principia, 1713.

SECTION I.

PHYSICS OF PONDERABLE MATTER.

Elementary Laws and general Statics, Chapter I—II. General Dynamics, Chapter III—IV. Simple Machines, Chapter V. Physics of Liquids at rest, or Hydrostatics, Chapter VI. Physics of Aërial Fluids at rest, or Pneumostatics, Chapter VII. General Properties and Laws of Fluids in motion, or Hydro and Pneumo-dynamics, Chapter VIII. Sonorous vibrations of Ponderable Bodies, or Acoustics, Chapter IX.

ELEMENTS

OF

NATURAL PHILOSOPHY.

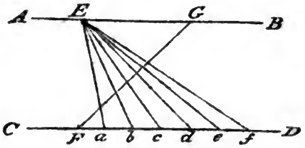
CHAPTER I.

GENERAL PROPERTIES OF MATTER IN ATOMS AND MASSES. (STATICS.)

Finite Divisibility of Matter, 1. *Essential Properties of Atoms—Impenetrability, Extension, and Figure*, 2—7. *Molecular Forces*, 8, 9. *Density*, 10. *Accessory Properties of Matter—Divisibility, Flexibility, Tenacity, Brittleness, Elasticity*, 11—17. *Inertia*, 18, 19.

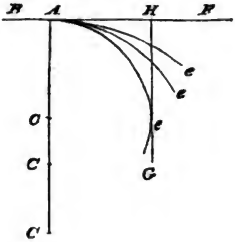
1. ALL varieties and forms of matter are similarly composed, being made up of an immense number of extremely and indeed inconceivably minute, indestructible particles, which, from their not admitting of further mechanical division, are termed *atoms*.* Some philosophers have, however, conceived that no true atom exists, and that all matter is capable of undergoing division to infinity, a statement capable of being satisfactorily proved, when limited to mathematical lines and points. Thus, let ABCD be lines drawn parallel to each other; draw the oblique line FG, and from F on the indefinite right line CD take any number of equal parts, as F*abcd*, &c. From E draw lines connecting this point to *abcde*, &c., cutting the oblique line FG; then, as the number of points *abe*, &c., on the line CD may be infinite, it follows that the line FG may be infinitely divided by lines connecting such points to E.

Fig. 1.



Another mode of illustrating the same position is by drawing two parallel right lines AC, GH perpendicular to BF, then from the points CCC, as centres, describe, with the distances, CA as radii, the circular arcs AE, AE, &c. Now the greater the radius AC, the smaller must be the part cut off from the line HG, and as the radius may be increased to infinity, the part GH may be diminished in a similar ratio, never becoming reduced to nothing, as the circular arc described with the longest radius can never entirely coincide with the right line BF. Consequently the parts of any magnitude GH may be in this manner diminished to infinity.

Fig. 2.

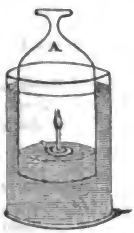


* A, and τέμνω, scindo.

Arguments of this kind ought, however, to be regarded as applicable only to mathematical lines and points, which, the former being without breadth and the latter without length,* can be regarded but as mental conceptions, and not physical existences.

2. The ultimate particles or atoms (1) of matter, possess the three *essential* characters of *impenetrability*, *extension*, and *figure*. Of these properties, the first flows directly from the definition of an atom, as it is obvious that nothing can be so impenetrable as that which is incapable of further division. When any solid body is immersed in a fluid, some portion of the latter is displaced, and thus, on a superficial view, might be supposed to be penetrated by the immersed body; it will, however, be found that no real penetration occurs, as a quantity of fluid becomes displaced, equal in bulk to the solid immersed (160). On forcing a nail or a knife into a piece of wood, the ultimate physical atoms of the latter are not penetrated, the instrument being merely insinuated into the interstices existing between the indivisible molecules. Again, air and all gases, although opposing a scarcely perceptible resistance to the passage of bodies through them, are really as impenetrable as solids. If a glass receiver A be inverted over a lighted taper fixed on a cork floating on the surface of water, it can be pushed to the bottom of the containing vessel, and the taper will thus continue to burn under water so long as sufficient oxygen is present to support combustion, as the included air from its impenetrability will prevent the entrance of water into the receiver. Upon this character of impenetrability depends the great physical axiom, that no two bodies can occupy the same space at the same instant of time.

Fig. 3.



3. The second character, or *extension*, is also a necessary consequence of the definition of an atom already given, as that which possesses a physical existence must necessarily occupy a portion of space, and possess sides and surfaces in relation to other atoms. The extension of bodies is expressed by the three dimensions of length, breadth, and thickness.

4. The third character, *figure* or *form*, is also essential to the existence of an atom, as nothing can be conceived as physically existing, unless it possesses some determinate shape, although this property is not sufficient of itself to prove the material existence of an object; for in shadows and spectral illusions, produced by various optical means, we have examples of figure or form without matter (577).

5. Of the actual form or size of atoms, nothing positive is known; it is, however, probable that they are spherical, but of their dimensions scarcely an approximation can be obtained by any means we are yet acquainted with. An ounce of gold can be drawn into wire several miles in length (11), and yet no flaw, or evidence of separation between its atoms can be discovered by the closest microscopic examination. Animalcules also exist, so minute that myriads can swim in a drop of water, and yet every individual possesses organs of digestion, circulation, and reproduction, each made up necessarily of an immense number of atoms. Chemistry affords us evidence of the excessive minuteness of atoms, for when several metals, as nickel, cobalt, or iron, are reduced from their oxides at the lowest possible temperature by means of a current of hydrogen gas, the state of division of the reduced metal is almost inconceivable. Each particle of metal slowly evolving its oxygen, forms a powder which may be considered as composed of ultimate atoms. These

* Euclid, Book I., defs. 1, 2.

are in every case less than $\frac{1}{100000000}$ of an inch in diameter, so that by a simple calculation it may be proved that a cubic inch of them would, if extended on a level surface so that they may touch, but not overlap each other, cover an area of 218,166 square feet, or more than five acres of ground.

6. Another illustration of the extreme minuteness of atoms is met with in the thin films of a soap-bubble. These present fine iridescent colored bands, and at the upper part of each, it is demonstrable that the thickness of the film just before it bursts cannot exceed $\frac{1}{4000000}$ inch (641); and yet even this thin layer is not composed of a single stratum of atoms; as it must consist at least of one atom of soap and one of water; the former composed of soda, stearic, or margaric, and oleic acids, in the simplest view that can be taken of its composition, and the latter made up of at least a molecule of oxygen and one of hydrogen.

7. The minute atoms composing *masses* of matter may be, and often are, chemically compound, although physically simple; thus a piece of marble may be divided into its ultimate molecules, each consisting of carbonate of lime, and here physical analysis stops; but by chemical analysis we can separate each of these atoms into carbonic acid and lime, the former being again chemically divisible into carbon and oxygen, and the latter into calcium and oxygen. In physics, therefore, an atom is regarded as simple when it cannot be further divided without separating its chemical elements.

8. Atoms are held together by means of a force denominated *attraction*, the firmness of their union being modified by the presence of an opposing force, termed *repulsion*, and upon the preponderance of one of these forces over the other, depend all the physical properties of matter, known as *hardness*, *softness*, *fluidity*, &c. The intensity of this molecular attraction varies considerably in different bodies, which thus acquire very varying degrees of tenacity (14).

If the mutual attraction of atoms be so considerable as to prevent a sharp body, as a knife, being inserted between them, the mass is said to be *hard;* but if so feeble as to permit their ready separation, the resulting mass is *soft;* and a *fluid* or *gaseous* body results when the intensity of the mutual attraction between the atoms is so far diminished, as to allow any substance to be moved between them without experiencing any considerable resistance. Thus the various states in which matter exists, as *solid*, *viscous*, *liquid*, or *gaseous*, merely depend upon the varying intensity of the molecular forces of attraction and repulsion. We may regard a solid body as one in which the mutual attraction of the constituent atoms exceeds their repulsion. A fluid is one in which the attractive and repulsive forces are equal; whilst in a gas or vapor, the repulsive force far exceeds that of attraction. These several states are readily convertible into each other by various mechanical means, and by alterations of temperature: thus, water at 32° and mercury 72° lower, are solids, the one being transparent, the other opaque. At ordinary temperatures both are liquids, whilst at 212° water, and at 670° mercury, become vapors or gases, both being transparent, these several changes depending merely on the greater separation of their atoms effected by the repulsive power of heat. The original volume of the fluid becomes amazingly increased by this separation of the constituent molecules. The following table shows at a glance their enormous increase of volume by vaporization.

1 cubic foot of	water expands into	1689·	cubic feet of vapor.
	alcohol . . .	493·5	
	ether	212·18	
	turpentine . .	192·15	

9. The most elastic gases can, by the application of sufficient pressure, be

compelled to assume a visible form; becoming liquids if the pressure be sufficient to bring their constituent atoms sufficiently near to each other.

Gases.	Pressure of atmosphere (181) required to condense them into liquids.	Temperature.
Sulphurous acid . .	2	45° Fahr.
Chlorine	4	60°
Carbonic acid . . .	36	32°
Nitrous acid . . .	50	45°

10. The density of matter in any of its three states is measured by the quantity contained in any given bulk, and is expressed by its specific gravity or specific weight, as compared with some body taken as a standard; thus if a given bulk of water contains 1,000 atoms of matter, a similar bulk of platinum will contain about 23,000; of copper nearly 9,000, of iron 8,000, and of glass about 3,000; these several numbers being identical with the specific weight or gravity of the respective substances (162).

Masses of matter, moreover, possess several properties which may be considered as accessory, all depending upon the different degrees of intensity with which the physical atoms are mutually tied together. Among the more important of these may be ranked *Divisibility*, *Flexibility*, *Tenacity*, *Brittleness*, *Elasticity*, *&c.*

11. *Divisibility*, or *Extension of Masses.* This character may be considered as well illustrating the extreme, and almost inconceivable minuteness of physical atoms; depending upon the immense, although finite number of parts into which a mass may be divided. Thus, an imperceptibly small portion of strychnia will render a whole pint of water bitter, and a single grain of the ammoniacal hyposulphite of silver will render intensely sweet 32,000 grains of water. One grain of iodide of potassium dissolved in 480,000 of water, when mixed with a little starch, will tint every drop of the fluid blue on the addition of a solution of chlorine. In all these cases, we have at once evidence of the extreme minuteness of atoms furnished by the divisibility of the masses of strychnia, silver, and iodine by means of solution. When animal or vegetable substances are burnt, they are neither consumed nor destroyed; their atoms are merely divided or separated from each other to form new combinations. Excellent illustrations of the same property are met with in many processes of art; a single pound of wool will furnish a piece of yarn 100 miles in length. Gold under the hammer is reduced to such a state of tenuity, that 360,000 of the leaves produced would, if piled on each other, only equal the thickness of an inch. Even this is far exceeded in the art of the wire drawer, who, in the most economical mode of preparing gilded silver wire, extends two ounces of gold over a length of 1,351,900 feet, or rather more than 768 miles. The exquisitely delicate wires of platinum made by the ingenious process of Dr. Wollaston, afford a remarkable instance of the extension of matter, no less than of the almost inconceivable minuteness of the component atoms. The finest of these wires is but one-three-millionth of an inch in diameter, and 140 of them placed together would just equal in thickness a single fibre of silk.

12. *Flexibility.* When any substance is capable of being bent in any given manner within moderate limits, by the application of sufficient force, it is said to be *flexible.* For a body to possess this property it is necessary that the attraction existing between one portion of its atoms should be capable of being partially overcome, and that between another portion proportionably increased.

Thus, let AB, CD, represent two rows of atoms situated at their normal distance from each other; on applying force sufficient to flex the whole into the curved form EF, GH, the arc EF will be larger than the arc GH, and consequently its atoms will extend over a larger, and those of the lesser arc over a smaller space than they did when in the rectilineal figure. That such a change in the relative distance of the atoms really occurs, is rendered evident by merely inspecting the figure of a thick wooden plank which has been allowed to become curved by its own weight. Let AB, CD represent the section of such a plank supported' at its extremities CD, it will be seen at once that the surface AB and CD represent two concentric curves, of which AB is the smallest; consequently the atoms nearest the surface AB must be more closely approximated than those nearest CD. The atoms lying in a line intermediate between AB and CD, undergo no change; the line EF, therefore, in which these lie, constitutes what is called the *neutral axis* of the body, and this portion might be excavated and removed without materially diminishing the strength of the plank.

Fig. 4.

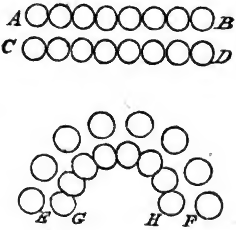


Fig. 5.

13. On this principle, hollow cylinders of different materials are employed instead of solid ones, when used as mechanical supports. Indeed, if all opposing causes in the shape of flaws, bad workmanship, &c., are absent, such hollow cylinders not only have the advantage of lightness and economy of material, but are found in practice to be actually stronger than solid ones of equal weight. Tredgold found that when the inner semi-diameter of the hollow cylinder is to the outer as 7 to 10, it will possess double the strength of a solid cylinder of the same weight.

14. *Tenacity*. This character is dependent upon the intensity of attractive force existing between atoms, being sufficient to oppose their ready separation to such an extent, as to cause the rupture, or fracture of the whole mass. Consequently, all flexible, ductile, and malleable bodies are tenacious; although many substances possess the latter property without the former. The tenacity of matter is well shown in the remarkable malleability of copper; for from a flat plate of this metal the skilful workman forms a hollow vessel without any joint or seam by the use of his hammer alone, and by well-directed and repeated blows, the vessel he has formed, however much differing in figure from the original plate, is everywhere of the same thickness. Tenacity varies extremely in different substances: metals afford the best examples of it; thus, a piece of steel wire of given diameter is capable of supporting without fracture 39,000 feet, or seven miles and a half of its own length. Wires of different metals of the same diameter, require different weights to overcome the mutual attraction of their component atoms, as shown in the following table, the figures representing the number of pounds weight required to break wires of the metals enumerated, one-tenth of an inch in diameter.

Metals.	Pounds required to produce fracture.
Bismuth	20·1
Lead	27·7
Tin	34·7
Zinc	109·8
Gold	150·07
Silver	187·13
Platina	274·31
Copper	302·26
Iron	549·25

Cables constructed of fine iron wires of from $\frac{1}{25}$ to $\frac{1}{30}$ inch in diameter, are stated to possess the enormous tenacity of 60 tons in each square inch. It is this wonderful tenacity which renders wires of this metal so applicable to the construction of light suspension bridges. The following table shows the tenacity possessed by different bodies calculated in tons weight.*

		Tenacity in tons, per square inch.
Wrought iron,	in wire $\frac{1}{20}$—$\frac{1}{30}$ inch in diameter	60 — 91
	in wire $\frac{1}{10}$ inch, diameter	36 — 43
	in bars (English)	25½
	in bars hammered	30
	in chains of six inch links	21½— 25
Cast iron		6 — 9¾
Steel, cast		44
	Damascus	31 — 44
Copper, cast		8½
	wire	27⅓
Silver, cast		18
	wire	17
Gold, cast		9
	wire	14
Platinum		17

15. Tredgold has shown that many solids will bear an enormous amount of pressure before they yield sufficiently to allow any permanent alteration in their shape. The figures in the following table represent the weight in pounds required to effect a change in the figure of a one-inch cube of the solids submitted to experiment.

Malleable iron	17,800 pounds
Cast iron	15,300
Brass	6,700
Zinc	5,700
Tin	2,880
Lead	1,500
Red Fir	4,290
Oak	3,960
White fir	3,630
Ash	3,540
Elm	3,240

Count Rumford found that a cylindrical roll of paper, with the folds glued

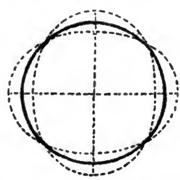
* Prof. Moseley's Illustrations of Mechanics, p. 395.

together, and presenting a sectional area of one square inch, would support a weight of 30,000 pounds!

16. *Brittleness.* This is obviously the converse of the last property of matter; it points out that condition of a substance, in which the attraction between its molecules is capable of being overcome by a comparatively slight force. Very hard bodies are often extremely brittle; thus, a piece of glass will scratch the surface of polished steel, and yet is the most brittle of substances, unless spun into exceedingly fine threads. This property is frequently acquired during the *hardening* of bodies, when their atoms are brought nearer each other's repulsive influence; thus soft steel is tenacious, yet a hard knife-edge is as brittle as glass; cast-iron is extremely brittle, and bar-iron is the toughest substance in nature.

17. *Elasticity.* A body is said to be elastic when, after being bent in any direction, it spontaneously recovers its former shape on the force which had altered its figure being removed; all elastic bodies must be so constituted as to allow a certain number of their atoms to be brought, at least momentarily, nearer each other than they previously were. If the body be a metallic rod, then, on being bent (see last figure (12), in the curved form EG, HF, it will have a tendency to assume its primitive rectilinear form on the removal of the coercing force, in consequence of the exertion of two forces, viz., attraction between the partially-separated atoms on the outside, and repulsion between the closely-approximated atoms on the inside of the curve. The rod will obey these forces, and after a few oscillatory or vibratory movements (77), will, if perfectly elastic, recover its primitive form. In this case, the change of form which brought into action the elasticity of the body is very obvious, from the curve produced by its flexure; sometimes this change of figure, even in the most perfectly elastic bodies, is not evident to the eye, on account of their figure; still such change does demonstrably take place. Thus a ball of ivory is elastic, and this property causes it to rebound from the floor when forcibly thrown upon it, its figure, on its impact, becoming altered and compressed, nor does it again become spherical until after it has for some instants been an ellipsoid, of which the greater diameter is successively horizontal and vertical, as shown by the dotted curves in the marginal figure. The force with which perfectly elastic bodies, when extended or compressed, tend to recover their form, is proportional to the amount of extension or compression to which they have been subjected; thus, for two, three, or four times the amount of compression to which the body has been subjected, an equivalent quantity of force will be exerted in attempting to recover its original figure. Different elastic bodies vary extremely in the extent to which they will yield without rupture; thus caoutchouc will yield considerably, and will afterwards very nearly regain its former shape, unless it has been stretched for some time. Glass threads, steel springs, unannealed copper and brass, are all elastic. Among the most elastic bodies are gases; these, on account indeed of their physical constitution (8), will permit, on the application of sufficient force, their atoms to be very closely approximated, again separating with rapidity, and even violence, on the removal of pressure; the air-gun and condensed air-fountain are examples of this property in atmospheric air (194).

Fig. 6.



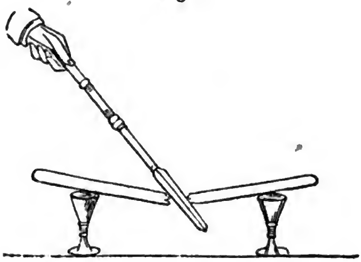
18. All forms of matter, whether in the atom or in the mass, are alike inert, and incapable, by the exertion of any spontaneous force, of changing their state or position: *wherever* a body is placed by any external cause, there it

must remain for ever, unless acted upon by some superior force. This property of matter is termed its *Inertia*, or resistance to a change of position.

The intensity of the force of inertia increases with the quantity of matter. The resistance experienced on first setting any body in motion, and the difficulty experienced in stopping it when moving, arise equally from this cause; for being absolutely inert, it follows that matter must retain its state of motion, as well as of rest for ever, unless acted on by opposing forces.

19. The following are examples of the force of inertia: in turning a winch a decided *resistance* is at first experienced to our attempts; this becomes gradually overcome, and then the wheel continues to move rapidly by the continued application of a force, just sufficient to overcome the resistance offered by the medium in which it moves, and the friction at the points of suspension. In a team of horses attempting to move a heavily laden wagon, an immense exertion of muscular force is required to overcome its *inertia*, but this once effected, the horses continue to draw that weight with facility, which at first they were scarcely able, by the utmost exertion of their physical force, to move. A traveler sitting in a coach, on the horses starting, is thrown backwards; his *inertia* opposing a resistance to his body acquiring at once the movement of the vehicle, and therefore tends to leave him behind; and on the coach stopping, he is thrown violently onwards, from the *inertia* of his body tending to retain the motion previously acquired. A bullet thrown at a pane of glass breaks it into thousands of pieces; but fired from a rifle at it, it merely pierces a circular hole, from the *inertia* of the glass rendering it impossible for every portion of the latter to acquire suddenly the rapid motion of the bullet, and consequently that portion only opposed to the point of impact is carried onwards, and participates in the rapid motion of the ball. A stick, whose ends rest on two wine-glasses, may thus be broken by a smart blow with a poker in its centre without injuring its brittle supports.

Fig. 7.



CHAPTER II.

NATURE OF THE ATTRACTIVE FORCES EXERTED BETWEEN MASSES OF MATTER, (GENERAL STATICS AND DYNAMICS.)

General Law of Attraction, 20, 21. *Cohesion*, 22. *Adhesion*, 23, 24. *Capillarity*, 25—33. *Endosmose*, 34, 35. *Diffusion of Gases*, 36—*of Liquids*, 37. *Gravitation*, 38—45. *Centre of Gravity*, 46—50. *Equilibrium*, 51—53.

20. ATTRACTIVE forces, capable of acting not only between atoms, but also between masses, exist; and form a very important subject of consideration. Molecular attraction of aggregation, which ties atom to atom, has been already alluded to. We have next to examine those forces which act between masses of matter; these may be divided into two sections, the first comprehending attractions at insensible distances, including *cohesion* and *capillarity;* the second, attractions at sensible, and often at immense distances, including *gravitation*.

21. All attractive forces, whether exerted between atoms or masses, diminish in intensity as we recede from the centres of the attracting molecules or masses, and obey one general law of *the attractive force being inversely as the squares of the distances between the attracting bodies.* Attraction is always mutual, and exerted by one body on another, *cæteris paribus*, in the ratio of their masses. As an example of the general law of attraction, let us suppose that two bodies, A and B, mutually attract each other when at a certain distance with a force equal to 1, at double that distance this force will be $\frac{1}{4}$ instead of $\frac{1}{2}$ of that when at a distance of 1, because the square of 2 is 4; at four times the distance, the force will be diminished to $\frac{1}{16}$, and so on. In the following table the upper line contains a series of figures representing the mutual distances of the attracting bodies, and the lower line a series of fractions representing the intensity of attractive force at those distances.

Distance	1	2	3	4	5	6	7	8	9	10	11	12	13	&c.
Intensity of attraction	1	$\frac{1}{4}$	$\frac{1}{9}$	$\frac{1}{16}$	$\frac{1}{25}$	$\frac{1}{36}$	$\frac{1}{49}$	$\frac{1}{64}$	$\frac{1}{81}$	$\frac{1}{100}$	$\frac{1}{121}$	$\frac{1}{144}$	$\frac{1}{169}$	&c.

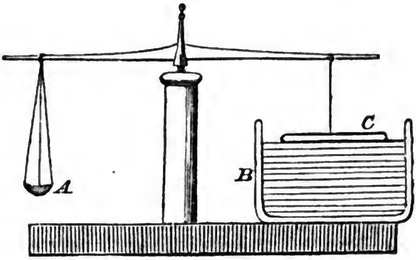
Attraction at insensible distances.

A. COHESION AND ADHESION.

22. Whenever two smooth surfaces are pressed together, a considerable resistance is experienced in attempting to separate them: this is owing to attractive force called *cohesion*, so termed from its causing bodies to cohere, or stick together. To observe the effects of this force advantageously, the surfaces of the bodies pressed together should be absolutely smooth; but as this is impossible, they should be polished and then smeared with a little oil to fill up any superficial inequalities: two plates of brass or glass thus prepared, and firmly pressed together with a screw-like motion, will cohere with such force, as to require a considerable weight to separate them. Two freshly-cut surfaces of caoutchouc will, on being pressed together, cohere so tightly that it is scarcely possible to separate them; and availing himself of this fact, the chemist prepares tubes of this valuable substance, applicable to numerous important purposes in his manipulations.

23. Cohesion takes place not only between the surfaces of solids when sufficiently approximated, but between solids and liquids: this variety of attractive force has been termed *adhesion.*

Fig. 8.



If from one arm of a balance, a plate of copper, C, be suspended, and carefully counterpoised by weights in the scale suspended from the opposite end of the beam, a very slight additional weight will cause either the plate or the scale to preponderate; place a basin full of water, B, under the plate C, in such a manner that the latter may just touch the surface of the water in B; on placing weights in A, a very considerable resistance is experienced to the separation of C from the fluid surface, owing to this cohesive attraction. With a circular plate of smooth copper, presenting an area of 6·75 inches, the weights required to overcome the attraction of the metallic surface for the water exceeded 1000 grains.

24. The intensity of this force, although constant, *cæteris paribus,* for the same solids and liquids, varies considerably in different kinds of solids or liquids; the following table represents the comparative intensity of the adhesive attraction exercised between different metallic surfaces and mercury, according to the researches of Guyton and Quetelet.

Metal Disks 1 inch in diameter.	Force of adhesion in grains.*	Disk of Metal.	Comparative force of adhesion.†
Gold	446	Gold	23·63
Silver	429	Silver	22·74
Tin	418	Tin	22·15
Lead	317	Lead	21·04
Bismuth	372	Bismuth	19·71
Zinc	204	Platina	14·98
Copper	140	Zinc	10·81
Antimony	126	Copper	7·52
Iron	115	Iron	6·10
Cobalt	8		

Gay-Lussac suspended a circular disk of glass, 4·6 inches in diameter, over surfaces of water, alcohol, and oil of turpentine. He found the force required to separate the disk from the fluids vary considerably, as shown in the following table:

* Guyton-Morveau, in Kastner's Experimentalphysik. Heidelberg, 1810.
† Quetelet, Positions de Physique, p. 104. Bruxelles, 1834.

Fluid.	Specific Gravity.	Adhesive force, in grains.
Water	1·000	414·7
Alcohol	0·8196	477·4
——	0·8595	505·1
——	0·9415	569·8
Oil of Turpentine	0·8695	523·6

The force which causes the disks in these experiments to adhere to the fluid, is identical with that which causes fluids to ascend in capillary tubes (26). The disk attracts an infinitely thin layer of the fluid on which it rests, and it is the molecular attraction of the mass of fluid for this thin layer adhering to the plate, which causes the resistance opposed to raising it from the surface of the liquid submitted to experiment.

B. CAPILLARITY.

25. If a plate or rod of any substance be plunged into a fluid capable of moistening it, as a plate of glass in water; the surface of the fluid, AB, instead of remaining perfectly horizontal, will rise to a higher level at the sides of the plate, as shown by the dotted lines, as if the water were attracted by the glass. If the glass plate be slightly greased prior to immersion, or be plunged into a fluid incapable of moistening it, as mercury, then a depression, instead of elevation, will take place on either side of the plate. If a plate of glass E, be plunged into mercury, CD, this apparent repulsion will take place, and appears to be owing less to any peculiar property of the fluid metal, than to the presence of a minute film or moisture adhering to the immersed solid, and preventing the actual contact of the mercury with the glass.

Fig. 9.

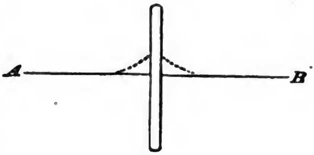
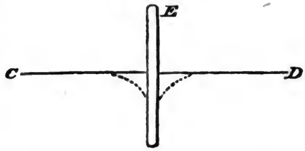
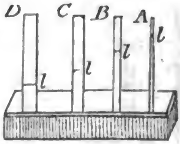


Fig. 10.



26. These phenomena are best witnessed by immersing glass tubes of small diameter in water tinted with archill or ink; the fluid will rapidly rise, attaining the greatest elevation in the narrowest or most capillary tubes. Thus it will rise much higher in A than in B, in B than in C, &c.; this mode of attraction, evidently a modification of the last described phenomena, is termed *capillarity* from its being most obvious in tubes of capillary or hair-like bores.

Fig. 11.



The height attained by fluids in these tubes is constant, and increases inversely as the diameters of the tubes; it bears no evident ratio to the density or specific gravity of the fluid employed in the experiment; for Muschenbröck* found that in tubes of equal diameter fluids rose to the comparative heights shown in the following table:

* Diss. physic. experiment. L. B., 1729.

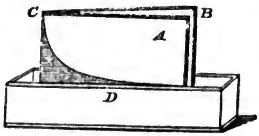
Names of Fluid.	Elevation.
Sulphuric acid	1·30
Sulphuric ether, containing alcohol	1·40
Anhydrous alcohol	1·80
Hydrochloric acid	2·07
Nitric acid	2·07
Oil of turpentine	2·58
Distilled water	3·40
Solution of ammonia	3·60
Solution of carbonate of ammonia	4·56

M. Gay-Lussac has ascertained that water, alcohol, and oil of turpentine, ascend in tubes of the diameter of ·05 inch to the following elevations:

Fluid.	Specific Gravity.	Elevation.
Water	1·000	0·92 inches.
Alcohol	0·8196	0·36 ——
——	0·8595	0·37 ——
Oil of turpentine	0·9415	0·39 ——
——	0 8695	0·39 ——

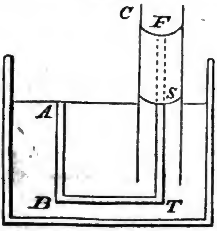
27. Capillary attraction comes into play equally between two plane surfaces immersed in fluids, as in the case of tubes. If two plates of glass, A B, touching at C, and separated at B, at a very small angle, be plunged into a trough, D, filled with colored water, the fluid will, after a short time, rise between the plates, attaining the greatest elevation where the glasses are closest approximated; and describing the curved surface well known as the hyperbola. The utmost elevation attained by this fluid in the arrangement is one half of that which would have taken place in tubes having their diameters equal to the distance between the plates; and being always inversely as this distance.

Fig. 12.



28. When a glass tube is immersed in a fluid, the attractive force of its internal sides determines the curve assumed by the surface of the water, but does not cause its elevation: this is owing to the action of the fluid itself; for let C be a capillary tube immersed in water, the attraction of this hollow cylinder causes the water to assume the concave surface S; let ST be an infinitely thin column of water, perpendicular to the centre of this curve, and corresponding to the axis of the tube, and A B be a similar column of water connected by an imaginary transverse portion BT; now, if no attraction were exerted at S, the two branches AB ST of this fluid rectangle would counterbalance each other, and no elevation ensue; but the fluid surface at S being attracted by the interior of the tube, the perpendicular pressure of the fluid column ST, at T, becomes less than that of AB at B; accordingly, AB preponderates, and presses through BT, the base of the column ST, and forces it to ascend in the tube to a certain elevation, as at F, and finally it remains suspended there, bounded by the same concave surface first produced by the attraction of the parietes of the tube.

Fig. 13.

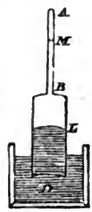


29. If a drop of water be placed in the wide end of a conical glass tube as at B, it will rapidly move towards the smaller end A. The drop on being placed in, becomes bounded by two concave surfaces, of which that nearest the apex of the tube is the most curved; the drop, therefore, moves towards the apex in consequence of the attraction of the sides of the cone for the water; being, according to Laplace, inversely as the radius of the curve terminating the fluid column.

Fig. 14.

Let ABD be a compound tube, consisting of a fine tube, having a capillary bore, inserted into a wider one. Let the latter be immersed in water; the fluid will rise to a certain elevation as L. Then let the whole tube be filled with water, and again immerse it, the fluid will fall to a certain point in the finer tube, as to M, and there remain suspended as perfectly as if the whole tube had been of the same diameter as the part AB. On refilling the tube, and immersing the end A, instead of D, in the water, the fluid will rapidly fall, and finally attain an elevation equal only to that produced if the whole tube had been of the same diameter as the wide portion, BD. This experiment proves most satisfactorily the accuracy of the law announced by Laplace, that it is the curve surface of the fluid, and not the attraction of the whole interior surface of the tube, which determines the elevation of the fluid.

Fig.15.



It is a very remarkable fact, that capillary attraction is capable of opposing the evaporation of fluids under its influence. Fine tubes of glass, containing as much water as they could under the influence of this force retain, have actually been suspended for months together in the summer's sun, without losing by evaporation any appreciable portion of their contents.

30. By means of capillary attraction, oil is raised in the wicks of lamps, water in bibulous paper, cotton threads, or any porous substance immersed therein; in fact, every phenomenon in which fluids insinuate themselves between particles of solids at small distances are referable to this force.

31. If, instead of using water in the experiments just detailed, a fluid incapable of moistening the surfaces of the solids immersed, be employed, the converse of the phenomena is observed, repulsion taking place instead of attraction. Thus tubes, or glass plates immersed in mercury in their ordinary state, cause a depression instead of elevation (22); or, if water be used, and the tubes are greased or rubbed over with resin, or still better, lycopodium, the same thing occurs. In tubes thus circumstanced, the depressed surface of the fluid always presents a convex instead of concave surface. This repulsion at small distances is well observed by rubbing the hand over with lycopodium, and immersing it in water; on withdrawing it, it will be found to be perfectly dry, not a drop of water adhering to it.

The following table shows the intensity of this capillary repulsion observed when glass tubes are immersed in mercury, after care has been taken by boiling the liquid metal in the tubes to expel all the air adhering to the surface of the latter. The amount of the depression of the mercury is always in the inverse ratio of the diameter of the tube.

Diameter of the tube.	Depression of the mercury.
0.60 inch.	0.002 inch.
0.50	0.003
0.45	0.005
0.40	0.007
0.35	0.010
0.30	0.014
0.25	0.020
0.20	0.029
0 15	0.044
0.10	0.070

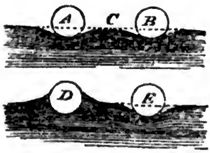
32. The adhesive attraction (23) is not only exerted between liquids and solids, but is equally active between the latter and invisible gases. Thin films of air adhere by virtue of their attractive force to the surfaces of most solids, and become very obvious in glass tubes when mercury is poured into them: the fluid metal, instead of closely and equally adhering to the inner surface of the tube, will be separated from it in several places by interposed bubbles of air, which adhere with the utmost obstinacy to the glass. This curious form of attraction is well shown in porous bodies, as cork, pumice-stone, charcoal, &c. When a fragment of either of these is immersed in water, and placed under the receiver of an air-pump, the escape of torrents of bubbles of air on exhausting the receiver (192) is very remarkable. The term *absorption* is generally applied to this power of porous bodies in attracting gases, and is remarkably intense in the case of freshly-burnt charcoal. Thus one cubic inch of this substance will readily absorb—

90	cubic inches of	ammonia.
86	"	hydrochloric acid.
55	"	sulphuretted hydrogen.
35	"	carbonic acid.
9.2	"	oxygen.
7.5	"	nitrogen.
1.7	"	hydrogen.

All bodies in the state of powder possess this property of absorbing air, which becomes obvious when they are immersed in water. Tolerably coarse iron-filings will thus actually float in water, if carefully sifted on its surface, being buoyed up by the adhering air, which appears like little globules of polished silver in the water.

33. A class of phenomena referable to *capillarity* is the apparent attraction and repulsion of small bodies floating on water, when placed at small distances from each other. If one of the bodies only be composed of a substance capable of being moistened by water, mutual repulsion will occur. But if both are incapable of being moistened, as two balls of wax, mutual attraction ensues. If the balls A B be of wax, or cork, rubbed over with lycopodium or resin, the water is repelled, and two depressions in which the balls lie are produced. If they are then placed sufficiently near each other, the repulsion of the opposed surfaces of the balls exerted on the water at *c*, will render its surface concave, and the balls, by the lateral pressure of the water beyond, will be pushed together, and appear to attract each other. In the second case, if the ball D

Fig. 16.



be of clean moistened cork and E of wax, the reverse takes place, the water being raised by attractive force on all sides of the first, and repelled by E. Therefore, on the balls being placed in contact, they appear to repel each other in consequence of D attracting the fluid, which is repelled by E, the latter being incapable of being moistened by the water.

34. Closely allied to capillarity are the phenomena of endosmose, and exosmose, discovered by Dutrochet. Whenever two liquids capable of being mixed with each other of different densities, are separated by a membranous or porous partition, two currents become established, one of a current of fluid proceeding from within to without, (exosmose, εκ and ωσμος, impulse,) and another in the contrary direction, (endosmose, ενδον and ωσμος.) If a glass tube closed at one end with a piece of bladder A, be partly filled with a solution of sugar, salt, &c., and immersed in a vessel filled with pure water to the same level; the fluid will rapidly rise in the tube B, the water having entered through the bladder by endosmose, and adding to the contents of the tube cause the fluid to be elevated much above its former level. If, now, the conditions be reversed, syrup being placed in C, and water in B, exosmose will occur, by which the tube B will become nearly emptied. As a general rule, liable, however, to several exceptions, it appears that fluids of less specific gravity have a tendency to pass through membranes and porous bodies, to mix with those of greater density, (provided they be miscible,) and consequently dilute them.*

Fig. 17.

35. These phenomena admit of a very simple explanation founded on the capillary attraction or repulsion exerted by the porous diaphragm upon the fluids exposed to its influence. In the case of a piece of bladder, this is readily moistened by water, but not by alcohol. Let the tube B be partly filled with alcohol, and then immersed in water. Endosmosis occurs and the fluid rises in the tube. The first action in this case is the attraction of the membrane to the water, whilst it repels the alcohol. A portion of water permeates the bladder, is immediately mixed with the alcohol, and is no longer attracted by the bladder. A fresh portion then enters, and this continues until the alcohol is considerably diluted.

The endosmosis or influx of fluid is always attended by an exosmosis or exudation of a certain portion of the liquid confined by the porous diaphragm. This may be illustrated by placing in the tube a solution of sulphate of iron, and immersing it in water. In a short time the solution will rise in the tube from the entrance of water; and if then a few drops of tincture of galls be added to the water in the external vessel, the purple color which is produced will satisfactorily prove that a portion of the solution of iron has really exuded through the membrane.

36. Analogous phenomena are also exhibited by gases or aëriform fluids. Thus, if a glass phial full of air has a piece of thin bladder tied firmly over its mouth, and be then placed in a jar of carbonic acid, the latter will permeate the membrane and enter the phial. The contents of the latter are consequently increased, the surface of the bladder becomes convex, and if sufficiently thin, will eventually burst. It has been demonstrated by Professor Graham, who has most elaborately examined these phenomena, that gases differ in their tendency to diffuse themselves through membranes or porous diaphragms. This tendency diminishes with the increase of density of the gas, being inversely proportional to this square root of the density.

Thus, if the diffusive power of atmospheric air be assumed as unity,

* Nouv. Recherch. sur l'Endosmose, &c., par M. Dutrochet. Paris, 1828.

the comparative diffusiveness of hydrogen, oxygen and nitrogen will be as follows:—

Gas.	Density.	Diffusive power.
Air	1.000	1.003
Oxygen	1.105	0.946
Nitrogen	0.972	1.014
Hydrogen	0.069	3.807

If a long tube be closed with a plug of dry plaster of paris, inverted in a cup of water, and filled with hydrogen gas, it will so rapidly permeate the plaster to diffuse itself in the air, as to produce a temporary vacuum in the tube. Water will consequently rise in the latter, and attain an elevation of six or seven inches in as many minutes.

37. The tendency of gases thus to diffuse themselves among each other, is a property participated in by liquids. This is, however, not without exception, as some, like oil and water, are not miscible with each other; and others, as ether and water, are miscible but in small proportions. In most cases of miscible fluids, an actual penetration of the mass of one fluid by the atoms of the other seems to occur; and the mixture consequently occupies less bulk than the fluids did when separate. Thus, if two glass bulbs A B, filled, one with water and the other with alcohol or sulphuric acid, be connected by means of an air-tight tube C passing from one to the other, the fluids will mix, and when the mutual diffusion or mixture is complete, will no longer fill both bulbs. On allowing the apparatus to rest for a few minutes in a vertical position, a space unfilled by fluid will be observed in the bulb A, in consequence of the mixture having been accompanied by a diminution in volume. If 180 parts of alcohol be added to 100 of water, the mixture will measure but 196 parts; the same bulks of sulphuric acid and water will, after mixture, measure but 185 parts.

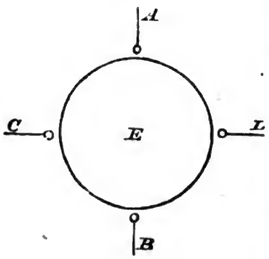
Fig. 18.

Attractions at sensible distances.

GRAVITATION.

38. When any substance, as a stone, &c., is permitted to fall from the hand, every one knows that it rapidly reaches the floor; and does not rise towards the ceiling, nor move laterally towards the walls of the room. A stone being mere inanimate matter, and consequently absolutely inert (18), this phenomenon cannot depend upon any *innate* tendency to reach the lower part of the room, as one of the essential properties of matter is its utter incapacity to change its position. Consequently, the simple phenomenon of the falling of any body towards the earth must arise from the exertion of an attractive influence or force emanating from the latter, and to this the name of *Gravitation* is applied in consequence of its causing that effect which we recognize by the term *weight:* the weight of any substance being merely a measure of the attraction of the earth for it. This form of attraction is exerted not only at compara-

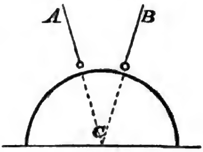
Fig. 19.



tively small, but at vast distances: thus this force acts as effectually on the planet Herschel at the distance of 1,800,000,000 miles as on the falling apple in which Newton is said first to have recognized its existence. If a mass of lead be suspended to a string, it will, as every one knows, when left free to move, point towards the earth: now the same thing occurs in India, in America, and at our antipodes; a fact proving at once that the lead does not obey a *natural tendency to fall;* for the plummets AB (fig. 19) point in opposite directions, as also do CD, according as they are situated at the opposite poles or at east and west; all pointing towards the centre E of the earth.

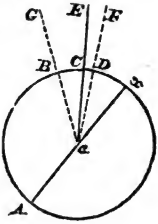
39. Gravitation, in common with other attractive forces, obeys most strictly the general law already announced (21), its intensity being inversely as the squares of the distances of the gravitating bodies. Thus our moon, which is placed at a distance of sixty of the earth's semi-diameters from its centre, is attracted according to this law with a force of $60 \times 60 = 3600$ times less than bodies are on the surface of our globe. The force of gravitation must always be considered as acting from the centre of any body from which it emanates. From this circumstance it is theoretically impossible for two plumb lines freely suspended, to hang perfectly parallel. Let A and B be two lines, each having a leaden ball suspended to it; they will point towards the centre C of the earth, and of course, instead of being perfectly parallel, will form an angle with each other, which at small distances is so slight that it may be almost neglected in reality, although it can never entirely vanish. In small distances, even to the extent of some hundreds of feet, the lines of gravity indicated by two plumb-lines may, on account of the magnitude of the semi-diameter of the earth, be regarded as parallel; but when these lines are some miles apart, their convergence must be calculated according to the curvature of the earth's surface; this will amount to about one minute in a geographical mile, and consequently to one degree in sixty miles.

Fig. 20.



Let ABCDx be a section of the earth at the meridian of Paris, and Ax its axis of rotation. Paris will be situated at C, and a plumbline freely suspended there will point in the direction ECc. Dunkirk will be at D at an angular distance of 2° 11′ 6″ from Paris, and its plumb-line will coincide with FDc. Barcelona will be at B at an angular distance of 7° 28′ 29″ from Paris, and a plumb line there will coincide with the line GBc, forming an angle of 9° 39′ 35″ with a similar plummet at Dunkirk.*

Fig. 21.



40. The intensity of the attraction of gravitation varies, not only with the mutual distances of the attracting bodies, but also with the quantity of matter contained in them. In this way the great centre of our universe, the sun, from its enormous bulk, its mass being greater than that of all the planets taken together, is capable of attracting even the most remote, as Uranus and Neptune, although placed at the enormous distance of hundreds of millions of miles. This force being *mutually* exerted between bodies, they always move to meet each other: hence when a book or a stone

* Pouillet, Elements de Physique. Paris, 1837, p. 62.

falls towards the earth, the latter rises to meet it: this motion is of course almost infinitely small, because the attraction of these bodies for the earth being, *cæteris paribus*, in the ratio of their masses, the enormous preponderance in favor of the earth would prevent its moving an appreciable distance to meet the stone, whilst it would be sufficient to enable our globe to attract the latter at a distance of several millions of miles. As a necessary consequence of this mutual attraction, elevated buildings and mountains might be expected to gravitate towards each other, an effect prevented by the superior attraction of the earth, which tends to keep them on the bases, and by the attractions at insensible distances which firmly bind their integrant portions together. For whenever gravitation and cohesive or capillary attraction are opposed, the latter within the limits to which they are confined are most energetic, instanced in the ascent of fluids in tubes (26) above their former level, and in opposition to the gravitative attraction of the earth. Still lateral attraction is exerted, for Dr. Maskelyne, in a set of experiments performed in 1772 near the mountain Shehallian in Scotland, found that a plummet was really drawn from the perpendicular by the attraction of the mountain to the extent of 54″. The same thing took place in the researches of the French astronomers, whilst engaged in America in determining the measure of the meridian; numerous sources of fallacy, arising from the lateral gravitation of their instruments towards the surrounding mountains, opposing themselves to the correctness of their results. The lateral attraction of Chimboraço, the loftiest of the Andes, although much diminished by the existence of an enormous volcanic cavity in its centre, was found by M. Bouguer to deviate a plumb-line 7″ or 8″ from the perpendicular. The mutual attraction of bodies free to move is beautifully illustrated in the celebrated Cavendish experiment,* which has lately been repeated by the late Mr. Francis Bailey.† In this noble experiment the attraction of a large mass of lead for a given mass of light matter was rigidly determined, and thus by comparing the attraction of the mass of lead for the light body with that of the earth, the mean density of the latter was determined to be 5·6747 times that of water.

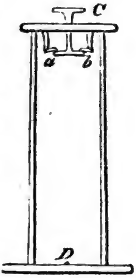
41. If no material obstacle interfere to check or impede the fall of bodies towards the earth, the attraction of the latter will cause them to move with equal degrees of velocity, so that all bodies falling from the same elevation at the same instant will reach the earth together. Daily experience appears, indeed, opposed to this, as heavy bodies seem to fall with greater velocity than lighter ones, and this on superficial reasoning might be expected, as attraction increases in proportion to the mass of matter. This objection vanishes when we recollect that, as matter is *inert*, force is required to set it in motion, and the *quantity of inertia being as the quantity of matter* (18), it follows that if an attracting force equal to four is sufficient to draw a quantity of matter equal to 100 pounds to the earth, four times that force will be necessary to draw 400 pounds with the same velocity, for as the mass of matter increases, its resistance to alter its state or position increases: a consequence necessarily flowing from the observations already made on the inertia of matter. Hence all bodies falling from the same height will occupy the same time in falling through a given space.

42. The apparent exception in the case of an extremely light body, as a feather, paper, gold leaf, &c., which, instead of falling directly towards the earth, floats in the air and descends by a circuitous route, admits of ready explanation.

* Phil. Transactions, 1798, p. 469.
† Mem. Astronomic. Soc., vol. 14th.

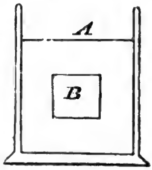
For this deviation from the direct course arises from the resistance of the medium through which the body moves, opposing itself to its direct downward motion. If this opposition on the part of the atmosphere be counteracted by compressing these light bodies into small bulks, as by rolling the paper or gold-leaf into a ball, then they will descend with equal velocity with heavier bodies. This is well shown by placing a piece of metal and a feather on the little brass shelves *ab*, fixed at the top of a tall glass receiver. These shelves move on hinges, and are kept in a horizontal position by means of the brass key C; on turning this key, the slides give way and the metal and feather fall, the former reaching the plate D sooner than the latter. Replace them, and exhaust the air by means of an air-pump; on now turning the key C, the feather and piece of metal will fall, and be found to reach the bottom D, at the same instant of time.

Fig. 22.



43. The ascent of vapors, and balloons into the air, like that of light bodies, as corks in water, is produced by the attraction of gravitation. For this attraction being greatest in proportion to the quantity of matter, the denser bodies, as the atmospheric air or water, are drawn forcibly downwards; and those containing a less quantity of matter in a given bulk, as the balloon in the former case, and cork or wood in the latter, are forced to rise by the denser fluid bodies sinking beneath them.

Fig. 23.



Let the vessel A be filled with water, and a solid body as B, be placed in it; both the fluid and the body B will be attracted by the earth. If B be denser than the same bulk of water, it will be attracted by the earth and will sink; but if it be less dense than an equal bulk of water, the latter will obey the gravitative attraction of the earth, and B will be forced to rise to the surface. Thus the floating of light bodies in fluids of every description, is a direct and legitimate consequence of the law of gravitation.

44. The spheroidal form of our earth, and of the planets of our system, appears also to result from this law. For as attraction is equal at equal distances, and emanates from the centres of the masses, we may conclude that the earth, when in a fluid or semi-fluid state, must necessarily have assumed the spherical form; because no figure has every part of the line bounding its periphery equidistant from the centre, except a circle: which would have been the exact figure of a meridian section of the earth, if disturbing causes arising from its rapid rotation had not interfered (59).

45. As weight is an *acquired* property of matter, and produced by an attractive force (38) emanating from the centre of our earth, it follows that a mass of matter would not appear so heavy on the top of a lofty mountain as on the earth's surface, because it will be there further removed from the centre of the earth. And accordingly it is found that a mass of lead, weighing 1000 pounds at the level of the sea, loses two pounds of its weight on being elevated four miles above the surface: and if carried to the surface of the moon, and thus be removed 240,000 miles from the earth, the attraction of the latter for it would not exceed five ounces.

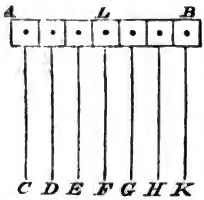
For this reason, bodies weigh heavier near the poles than at the equator, on account of the former being nearer the centre of the earth than the latter; and if it were possible to place any body in a cavity at the centre of the earth,

it would be equally attracted on all sides, and consequently remain suspended in space, like the fabled coffin of Mahomet.

CENTRE OF GRAVITY.

46. A little reflection on the nature of gravitation will indicate the existence of a point in every substance, at which the attraction of the party for every portion will be equally balanced; and which, if supported by mechanical means, will place the whole body in a state of stable and firm equilibrium (52). This point is termed the *centre of gravity* or *centre of inertia*, as it is the spot where the whole vis inertiæ of the mass may be supposed to be concentrated. Let AB be a bar of any substance divided into seven imaginary parts, the dots in the centre of each representing the centre of gravity of each portion. The attraction of the earth for each of these parts may be represented by a series of parallel right lines, CDEF, &c., and if each component portion be of equal bulk and density, the attraction of the earth for each will be equal. Under these circumstances, three lines of attractive force of equal intensity are situated on each side of L; and if a sufficiently strong prop be fixed in the direction LF, the whole body will be supported. The support LF must be strong enough to resist the attraction of the earth for the seven portions of AB, represented by the seven lines, which attraction is of course equal to the *weight* of the bar (38). The spot in the centre of the portion L of AB is called the *centre of gravity of the whole bar*, and at this point the attractive force of the earth, represented by the lines CDEGHK, may be supposed to be concentrated in the centre line F. The term, *centre of parallel forces* (116), is from its position often applied to this point.

Fig. 24.

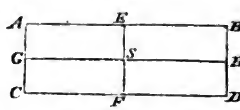


Mode of determining the centres of gravity of differently formed bodies.

47. (A.) The centre of gravity in a right line, composed of similar particles of matter, is its middle point. In the line AB, the point C is the centre of gravity.

Fig. 25.

Fig. 26.



(B.) The centre of gravity of a parallelogram is the point where lines bisecting two of its sides intersect each other. In the figure ABCD, bisect AB and CD by the lines EF GH. The point S, where these lines intersect, corresponds to the centre of gravity.

In a triangle, (fig. 27,) as ABC, the centre of gravity is found by bisecting AC, and AB at DE, connect DC and BE; the point S, where these lines intersect, is the centre of gravity of the figure.

(C.) In any other figure bounded by right lines, the centre of gravity may be found by dividing it into triangles, and finding the centre of gravity of each. Thus, let ABCDE (fig. 28) be the figure in question, divide it into the triangles ADC, ABC, and AED, find the centre of gravity of each in the manner already described (41). Let *abc* be these centres. Then join *a b*, and bisect this line

Fig. 27.

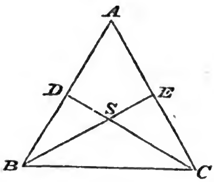
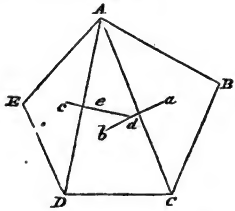


Fig. 28.



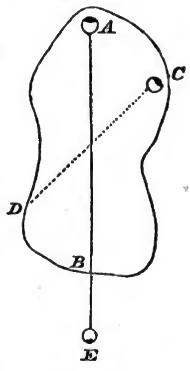
at *d*, in such a manner that the part *db* will bear the ratio to *ad*, as the triangle ABC does to the triangle ADC. The point *d* will thus be the centre of gravity of the figure ABCD. In like manner connect *d* to *c* by the line *ced*, and bisect this at *e*, in such a manner that *ce* will bear the same proportion to *ed* as the sum of the triangles ABC and ACD does to the triangle ADE, and *e* in the middle of the line *cd*, will be the centre of gravity of the whole figure.

(D.) In a circle, the centre of gravity is in its geometric centre; and in an oval, at that point where its transverse and longitudinal diameters intersect.

In all these cases the density of the matter composing the figures is supposed to be uniform, and its thickness inappreciable.

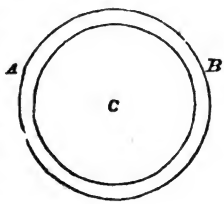
48. If a body be freely suspended by any point, it will remain at rest when a perpendicular line let fall from that point passes through its centre of gravity. This law affords a ready mode of determining the centre of gravity of any body by experiment. For let ACBD be an irregular-shaped body, as a board freely suspended at A, a plumb-line ABE hanging on the same support. The attraction of the earth will cause the line AB to hang perpendicularly downwards, and acting on the centre of gravity of ACBD, will cause that to fall in some part of the figure covered by the line AB, as at this point or centre all the effect of gravitation may be supposed to be concentrated (46). With a pencil draw a line AB on the board, and suspend it with the plumbline from another point, as C. The force of gravitation will now cause the board to assume a state of rest in another direction, still having the centre of gravity in the course of the vertical line described by the plumbline. Let this line be CD, and the point where AB DC intersect each other, corresponds to the centre of gravity of the figure ABCD.

Fig. 29.



49. The centre of gravity is by no means necessarily placed in the body itself; in a ring, for example, as AB, this point will be the centre C, and consequently in the space midway from every portion of the solid.

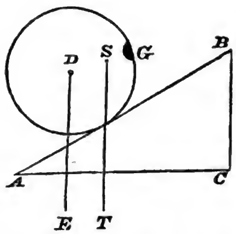
Fig. 30.



50. If a body be not of uniform density, the centre of gravity is not situated in the places above described. In a homogeneous circular figure, it corresponds, as above stated, with the geometric centre; but in one of unequal density in different parts, it becomes eccentric, often considerably so.

Let ABC be an inclined plane, and a plain circular figure DSG be placed upon it; if this be composed of matter of equal density, D will be the centre of gravity, and being attracted by the earth in the direction DE, falling below the point supported by the plane, the circular body will necessarily roll down.

Fig. 31.

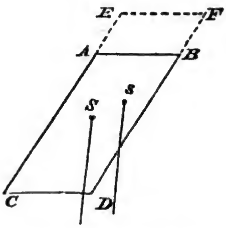


Let the portion G of the figure DSG be composed of some dense matter, as lead, the remaining portion being of wood, as alder; then a bulk of the latter, weighing 800 grains, will correspond in size to a mass of the former weighing 11,350 grains: those numbers, being in the ratio of the respective specific gravities or densities of the two bodies. The attraction of the earth will now act very differently on the circular figure D, for the centre of gravity will no longer be at the geometric centre, but at a point nearer G, as at S. Gravitation will act on S in the direction ST, causing it to assume the lowest point, the point S will obey this attraction, and the circular figure D will roll up the inclined plane; remaining at rest when a line let fall from the centre of gravity S passes through the point supported by the plane.

The analogous phenomena of a double cone moving up a double inclined plane, and of a billiard ball moving up two inclined rods, admit of a similar explanation.

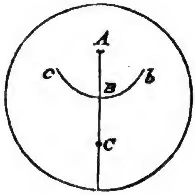
51. No body can be in a state of permanent equilibrium unless a line, falling from its centre of gravity, passes through the point of support. Thus in the figure ABCD, S represents the centre of gravity, and a line falling from that point passes through the base, which is supported by the table; the figure therefore stands safely. But place on its summit another piece, AEFB, the centre of gravity will be raised to *s*, and as a perpendicular line drawn from that point falls beyond the supported base, the body necessarily falls. Hence the danger of loading wagons too high, and of building walls, if necessarily inclined, too lofty; the leaning towers of Pisa and Bologna may, accident apart, stand forever, as long as a perpendicular line drawn from their centres of gravity falls within the bases of the buildings. This is indeed the case with both these remarkable structures, for the tower of Pisa is 315 feet high, and has an inclination of 12·4 feet from the perpendicular, and that of Bologna with an elevation of 134 feet, has an inclination of but 9·2 feet.

Fig. 32.



52. A body, unacted upon by other external forces except gravitation, will be in a state of *equilibrium* when its centre of gravity is supported (46).

Fig. 33.



If the body be circular, and B its centre of gravity, it will be in a state of *stable* or *steady equilibrium* if supported by an axis passing through A, for a perpendicular line produced from this point will pass through the centre of gravity; and if the body be moved, it will, after a few oscillations, in which B will describe the circular arc *c*B*b*, recover its former position. If, then, the axis be passed through B, the body will be in a state of *indifferent equilibrium;* for

the point of support corresponding with the centre of gravity, it will remain at rest in whatever position it be placed. Lastly, if an axis be passed through C, the body will be in a state of *unstable equilibrium*, for it can only retain this position as long as a vertical line produced from B passes through C; and as soon as the slightest deviation from this position occurs, on the application of the smallest force, the body will move round, until B falls under the point of support. Thus, for a body to be in a state of *steady equilibrium*, its centre of gravity must occupy the lowest possible point.

53. The stability of a suspended body, and consequently the resistance it opposes to disturbance of its equilibrium, increase with the distance of its centre of gravity below the point of support. Hence in the construction of very delicate balances, it is necessary for the centre of gravity to be but just below the point of support; otherwise so great a force would be required to disturb the equilibrium of the beam as to render its indications in the estimation of small weights nearly useless.

CHAPTER III.

ON MOTION.

Species of Motion, 54. *Newtonian Laws*, 56—61. *Centrifugal Motion*, 57. *Figure of the Earth*, 59. *Action and Reaction*, 61. *Reflexion of Motion*, 62. *Composition of two Forces*, 63, 64—*of several Forces*, 65. *Resolution of Motion*, 66. *Velocities of moving Bodies*, 70. *Momentum*, 71. *Collision*, 72—76. *Vibrations*, 77, 78—*Forms of*, 79, 80—*Isochronism of*, 81. *Phases, nodal points*, 82, 83—*Velocity of*, 84. *Transverse and Longitudinal*, 86.

54. In the preceding chapters we have confined ourselves to the consideration of matter in a state of rest; we have next to investigate the properties of matter in motion, constituting part of the science of Dynamics.

By motion we understand the act by which a body changes its position. It has been divided into several species; thus a body is said to be in *absolute* motion when it is actually moving from one part of space to another, instanced in the movements of the planets; and to be in a state of *relative* motion, when it is moving with respect to some one body and at rest with regard to another: thus a man standing in a sailing vessel is in motion with relation to the shore, and at rest in relation to the several parts of the ship; in this case also his motion is said to be *common* with that of the vessel. Besides these, there are some other divisions of motion which it is important to understand; thus the motion of a body is *uniform*, when it passes over equal portions of space in equal times; it is *accelerated*, when the successive portions of space passed over increase, when they diminish it is said to be *retarded*, and when this increase or decrease of motion is constant, the motion is said to be *uniformly accelerated* or *retarded*. The motion of any body is *swifter* or *slower* in proportion as the space passed over in a given time is greater or less. The degree of rapidity with which a body moves is termed its *velocity*, and is measured by the space passed over in a given time.

55. In consequence of the *inertia* of all bodies (18), force must be applied to cause them to assume motion. If it be merely intended to cause the body

to move in the same horizontal plane which it previously occupied, the applied force must be sufficient to overcome the innate resistance of the body to any alteration in position, or *inertia*, and the friction of the supporting body. But if it be intended to place the body on a higher horizontal plane than it previously occupied, the applied force must be sufficient to overcome also the attraction of the earth, or force of gravity (38).

56. The simplest principles to which the phenomena of motion can be reduced have been arranged by Newton in the form of three axioms or laws; well known as the Newtonian laws of motion.

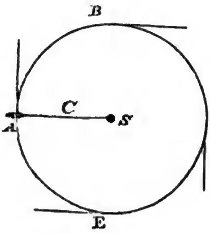
LAW I.

A body at rest will continue at rest; and if in motion, will continue to move in a right line, unless acted upon by some external force.

This law is a necessary consequence of the *inertia* of matter (18). The second part, however, referring to a moving body never assuming a state of rest until acted upon by external force, might at first be doubted; but a little reflection on the commonest phenomena presented by moving bodies will expel this doubt, and demonstrate the truth of the Newtonian axiom. The very *inertia* (8) which a body when at rest opposes to any applied force which tends to put it in motion, equally opposes its coming to a state of rest when once in motion. Therefore, whenever a body in motion comes to a state of rest, we may safely infer that some external force has been exerted to check its progress through space. The chief external causes checking the motion of bodies, are: 1. *Friction.* If a ball be thrown along a common road, its motion from its encountering so many obstacles, becomes obstructed, and it soon stops; on a smooth bowling-green, there being less friction, the ball moves to a longer distance: and still farther on a smooth sheet of ice or level pavement, from the great diminution of friction. 2. *Resistance of the atmosphere.* This has been already referred to as a powerful cause in checking motion; it may be very satisfactorily proved by causing a wheel accurately balanced to rotate in air, and in the vacuum of an air-pump; it will be found to continue in motion for a much longer time in the latter than the former. 3. *Gravitation.* This is by far the most important source of opposition to the continuance of motion, for whether a body be projected vertically upwards, or horizontally, the attraction of gravitation will ultimately cause it to stop and fall towards the earth.

57. In consequence of the *inertia* of bodies causing them to persevere in rectilinear motion, it is found that, when revolving in a circle, they constantly endeavor to recede from the centre. This is termed the *centrifugal* or centre-flying force. If a ball affixed to a cord C, be made to revolve rapidly in a circle, from a fixed point S, as a centre, it will describe the circle ABE. If, whilst rapidly moving, the cord C be cut with a sharp knife, the inertia of the ball will cause it to continue in motion, not, however, in a circle, but in a right line corresponding to a tangent to the circular path it described whilst the line C was entire. The force which caused A to fly off in the direction of a tangent is the *centrifugal* or centre-flying force: and the cord C represents the direction of a *centripetal*, or centre-seeking force. Thus, considering the circle to be composed of an infinity of planes, the ball will tend to follow the direction of one of these planes, and rush off at a tangent to the curve. This

Fig. 34.

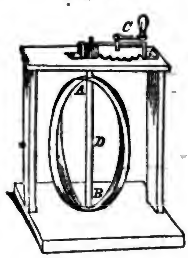


circumstance, taking place the instant the force which binds A to the centre is overcome, shows at once that the centrifugal motion is the result of the tendency which bodies possess of moving in rectilinear paths, and is not owing to the development of any new force.

58. We see magnificent examples of this force in the revolution of the spheres of our universe. Here the earth and other planets revolve round the sun as a centre, with enormous velocity, everywhere tending to rush off into infinite space in the direction of a tangent to their elliptic orbits, a state of things of course equivalent to universal desolation and destruction, and prevented only by a powerful centripetal force. The latter is here represented by the gravitative attraction of the sun, by which all the planets tend to gravitate towards his centre. Equally balanced between these opposing forces, the elements of our universe have revolved for myriads of ages around the great centre of our system, presenting a wonderful spectacle of infinite harmony and wisdom.

59. On our own globe we have a remarkable instance of the effects of this force, from its revolving on its own axis at the rate of 13·5 miles in a minute. An energetic centrifugal force becomes generated at the equator, by which portions of the earth tend to rush off into space; this is prevented by the centripetal force of gravitation acting from the centre of the earth. Still this has not been without its influence, for at an early epoch, probably during a semi-fluid state of our globe, a considerable bulging out occurred at the equator, and a corresponding flattening at the poles; so that the equatorial diameter of the earth is 17 miles greater than its polar diameter. This alteration in figure admits of an easy illustration, by rapidly revolving two elastic iron hoops placed transversely. These are fixed to the iron axis at A, and are loose at B; on turning the handle C, so as to revolve them rapidly, the movable ends of the hoops will rise half-way up the axis to D, and will bulge out at the sides. Thus representing the figure of a hollow flattened spheroid, so long as the rapid motion continues; when this ceases, the loose ends of the hoops will descend and regain their original figure. On this account bodies weigh less at the equator than at the poles: 1000 pounds at the latter corresponding to 995 at the equator, from the increased distance from the centre of the earth (45).

Fig. 35.



The projection of a stone by a sling; heaving the lead at sea; the scattering of drops of water from the wet revolving carriage wheel, or housemaid's mop; are so many familiar examples of this force.

LAW II.

60. *Change in the direction of motion is always proportioned to the force applied, and will take place in a right line with the impressed force.*

Having, in the preceding observations, shown that all motion must result from the application of force, we now find that such motion will be proportioned to the force applied; and thus, if a force equal to 2 produces a certain amount of motion, twice as much will be produced by a force of 4, and three times as much by a force of 6. If the direction of the force be horizontal, the movement will be in that direction; and if oblique, the direction of the motion will be equally so. The motion will be increased or diminished in the same proportion as the applied force. The full effect of the force acting

on a body free to move, is exerted only when applied in a direction perpendicular to the body. In any other direction a part only of the applied force is active.

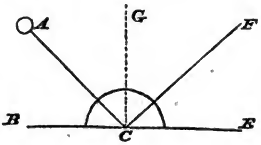
LAW III.

61. *All action is attended by its corresponding reaction, equal in force and opposed in direction.*

The existence of this law is so obvious that a very few examples will be sufficient to prove its universality. If a person presses a stone with his finger, he experiences a resistance arising from the reaction of the stone producing a counter pressure. A horse drawing a load forwards, is pulled backwards by the weight to which he is connected. A bird, in the act of flying, strikes the air downwards with its wings, and produces a reaction sufficient to support itself in the medium in which it lives. In swimming, a man strikes the water downwards, and its reaction rises and causes him to float. In firing a rifle, the exploding powder, which gives to the ball its fatal velocity, produces the recoil of the piece.

62. This law is also the cause of the well-known phenomenon of the *reflexion of motion.* If any body, as a marble, or any other tolerably elastic body, be thrown against a fixed substance, it strikes it with a certain degree of force, and the reaction of the fixed body throws the ball back again with equal force, providing no opposing causes interfere. If the ball be projected in a direction perpendicular to the plane of the fixed body, the reaction will drive it back in the direction of the path it described whilst advancing towards it; but if it move obliquely, the reaction will reflect it with an equal obliquity, but in an opposite direction. Let A be the moving body projected in the direction AC against the fixed obstacle BCE; the reaction of the latter will reflect the ball in the direction CF, forming an angle with the plane of the fixed body, equal to that formed during its approach to C. The angle formed by the line AC with the perpendicular GC is called the *angle of incidence;* and that by the line FC with GC, is called the *angle of reflexion;* and as the angle ACG is equal to the angle GCF, we deduce the general law, that the *angle of incidence is always equal to the angle of reflexion;* a law applying not only to the movement of ponderable, but of imponderable matter, as light (566).

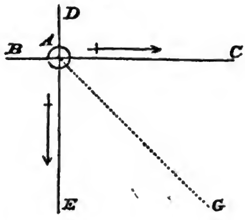
Fig. 36.



63. From the Newtonian laws of motion, we learn that the application of one force can only produce movement in a straight line; and that two or more forces are necessary to produce curvilinear motion. We have next to consider the effects resulting from the simultaneous actions of two or more forces on bodies free to move.

Let A be a ball of any substance, acted upon by two equal forces in directions at right angles to each other; and let BCDE represent the directions in which these forces would respectively move the body A. It is obvious that A cannot obey both these forces at the same time without separating into two portions; it therefore takes a path midway be-

Fig. 37.

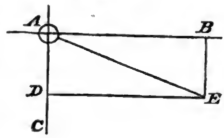


tween them in the direction of the dotted line AG; which is termed the *resultant* of the two separate forces BC DE.

If the two forces act on A, in directly opposite directions, the ball will of course remain at rest, providing the forces are equal; but if one $= F$ exceeds the other $= f$, then the ball will obey the excess of force $F-f$, and will move in the direction in which F acts.

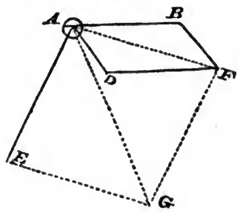
64. When the forces are unequal, the resultant path of the ball may be readily determined. Let A, as before, be the ball, acted upon by two forces at right angles to each other; let AB represent the direction of one, and AC of the other force. Suppose that the force acting in the direction AB is equal to 3, and that in the direction AC to 2. On the line AB, take off from a scale of equal parts the distance 3, and on AC the distance 2. Describe DE parallel to AB, and BE parallel to AD; then join AE, and this line will be the path taken by the ball A, and is the *resultant* of the two forces AB AD.

Fig. 38.



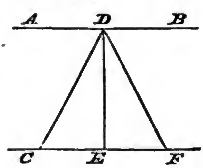
65. When three or more forces act upon a body, their *resultant* may be found in a similar manner; for, having found the resultant of two forces, in the manner already described, adopt this for the side of a fresh parallelogram, the other being furnished by the line of direction of the third force. Thus, if A be acted upon by the forces AB, AD, AE; find the resultant of AB, AD, in the usual manner, this will be the dotted line AF; then measuring on AE a distance equivalent to the force acting in that direction, draw EG parallel to AF, and FG to AE. The diagonal of this parallelogram AG will be the *resultant* line, in which the combined action of the three forces will ultimately act.

Fig. 39.



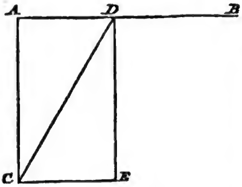
66. In consequence of the *resultant line* pointing out the ultimate effect of all the forces exerted, all these cases are termed examples of *composition of force*, or *motion*; and each of the quadrilateral figures described by the lines in the above diagrams, is termed a *parallelogram of forces*. Conversely, as we obtain a *composition of force* by the simultaneous action of two forces in different directions, so we can, by what is termed the *resolution of force* or *motion*, resolve or refer the production of certain rectilinear motions to the simultaneous exertions of two different effects. Thus, in the case already mentioned (62), when a moving ball strikes a fixed obstacle, neither being perfectly inelastic, the angles of reflexion and incidence are equal; the reflexed motion DF of a ball placed at C, after striking D, may be accounted for. For the force by which the ball at C moves obliquely to D, may be resolved into two, one acting in the direction CE, parallel to the plane, and the other DE, perpendicular to it. As both these forces are virtually in action when C strikes D, the reaction of the latter will develop both, and tend, the one to move the ball in the direction DB, the other in the direction DE. It being impossible for the ball to obey both forces simultaneously, it follows the resultant line DF, which forms, with E, an angle equal to that of CDE, in accordance with the general law.

Fig. 40.



67. If a perfectly elastic body impinge upon a hard and fixed plane obliquely, it will be reflected from it in such a manner, that the angles of reflexion and incidence will be precisely equal, as has been already demonstrated (62). But if both the striking body and fixed plane be perfectly hard (78) and inelastic, then, after its oblique incident, the body will not be reflected, but will move along the plane.

Fig. 41.



Let ABD be the plane, and CD represent the path of the moving body; draw DE perpendicular, and CE parallel to AB. It is obvious, that CD may be resolved (66) into the two forces CE CA, as in the case of collision of elastic bodies (62); the motion CA is employed in carrying the body directly towards the plane, which, being perfectly hard, annihilates this direct motion. The other motion CE is employed in carrying the body in a direction parallel to the plane, and of course will not be destroyed by the impact; and no force existing to separate, or reflect the body from the plane, it will move along it in the direction DB. In this case, calling the velocity before impact V, and that after, v, we have

$$V : v :: CD : CE.$$

68. In the resolution of forces, the whole amount of force exerted is necessarily increased. For in the last example, the force which propels the ball from C to D is resolved into CE, ED, which together are greater than CD; the estimated effects of forces, however, do not become affected by either composition or resolution when estimated in given directions. (*Wood's Mech.*, 66.)

69. Illustrations of the action of one force on a body are too familiar to require notice; of two forces, we have an example in a boat tending to be carried westward by the tide, whilst the boatman, by the aid of his oars, attempts to direct its course northward; supposing both these forces to be equal in intensity, the boat proceeds in the direction of the diagonal of a parallelogram, two of whose sides represent the direction of these forces, or north-west. A steam-vessel, whose paddles tend to propel the vessel northward, whilst the wind blows eastward, and the tide running in a third direction, illustrates the application of these forces; for the vessel, not being able to obey all three forces simultaneously, sails on her way in the direction of a resultant line of the whole.

70. When forces of equal intensities act on bodies free to move, they cause the latter to move with velocities, which are in the inverse ratio of their masses, or quantity of matter composing them. So that if equal charges of exploding powder be made to act upon bullets, whose volumes, supposing them to be of equal density, are as 1, 2, 3, 4, 5, 6, &c., it will cause them to move with velocity varying reciprocally as the numbers 1, $\frac{1}{2}$, $\frac{1}{3}$, $\frac{1}{4}$, $\frac{1}{5}$, $\frac{1}{6}$, &c., so that the bullet whose volume is equal to 5, will be propelled with a velocity one-fifth of that with which one whose volume is equal to 1 is projected. Hence. for an equal force, the masses of the projectile multiplied by the velocity, gives the same number, and this is termed the *quantity of motion;* and a force double or triple that of any other, will produce two or three times the quantity of movement. From these facts the following laws have been deduced.

(A.) Forces are to each other as the quantities of motion they produce, or as the masses multiplied by the velocities.

(B.) For equal masses, the forces are to each other as the velocities they produce.

(C.) For equal velocities, the forces are to each other as the masses on which they act.

71. All bodies, when moving either under the influence of attraction or any impressed force, oppose a much more considerable resistance to their being stopped, and strike an opposing obstacle with a much greater degree of violence than their mere inertia (18) will account for. This arises from the impetus acquired by the moving body during its passage—it is termed *momentum*, which, velocities being equal, increases in the ratio of the mass of matter, and in the ratio of the velocities when the masses are equal. Consequently, the momentum of any moving body is found by multiplying its mass by its velocity. A light body will, by having its velocity, and therefore its momentum, increased, strike an obstacle with as much force as a heavier one animated with a slower motion. A cannon ball, of 3 pounds weight, possessing a velocity of 300 feet in a second, will possess as much momentum, and strike any opposing substance with as much force, as one of 30 pounds moving at the rate of 30 feet per second, for $300 \times 3 = 30 \times 30$.

This fact explains why large masses of loaded ships or icebergs, although moving but slowly, are capable of exerting such enormous force upon bodies with which they come in contact, and, on the other hand, shows to what cause, the ball projected from a musket, notwithstanding its infinitely smaller bulk, owes its destructive powers.

72. The force with which one moving body strikes another, is termed percussion, or collision: and is the same with momentum (71). When two moving bodies come in contact, their collision is said to be *direct*, when a right line connecting their centres of gravity passes through the point of impact. In speaking of the collision of bodies, a substance is said to be perfectly hard, when it is utterly impossible by the force applied to separate or alter the position of its particles.

When the collision of two perfectly hard bodies is direct, they will, after impact, either remain at rest or move on uniformly together. Let these bodies be called A and B, and let A overtake B, both moving in the same direction, then A will continue to accelerate B, and B to impede A, until both have acquired the same velocity, after which they will move on uniformly together. But if they move in opposite directions, and their momenta (71) be equal, they will mutually stop each other, and attain a state of rest after collision. If the force of A is greater than that of B, the whole velocity of B will be destroyed, and as some of the motive force of A will still continue, it will act on B, until both, as in the first case, move on uniformly together. In both cases, the common velocity of A and B, after collision, may be found by dividing the whole momentum before impact (estimated in the direction of either motion) by the sum of the masses of matter.

73. When collision takes place between perfectly elastic (17) bodies, the velocity gained by the body struck and that lost by the striking body, will be twice as great as if the bodies were perfectly hard and inelastic. On impact first taking place, the same state of things occurs as in the case of collision of perfectly hard bodies; and as soon as one body has produced the full effect of collision on the other, they both become compressed by the blow, and, recovering their former shape in consequence of their perfect elasticity, react on each other; each body receiving an impulse, equal to that which caused its compression.

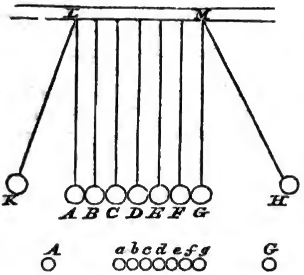
74. When two perfectly elastic balls of equal bulk move towards each other in a direct line, they will, after collision, recoil with inverse velocities. If moving in the same direction, but with different velocities, the slowest ball first, then the swiftest will overtake it, and after collision, they will both continue to travel on, but with inverted velocities; the ball which traveled swift-

est before collision, will lose, and the other gain, velocity. Lastly, when an elastic body strikes against another equally elastic, but at rest, it will, after collision, become stationary, the latter moving on with the velocity of the impinging body.

75. Bodies possessing but imperfect elasticity, as soft substances, oppose more effectually than any others the momenta of bodies in motion, in consequence of their yielding, in a greater or less degree, to the force of collision without reacting upon it; and thus opposing to the shock of the moving body, a gradual resistance instead of a sudden one, as in the case of perfectly hard substances. Thus they receive, as it were, the force of momentum, in several instants of time, instead of but one, and lessen the impetus of the shock. Hence a feather bed or sack of wool will stop a bullet much more effectually than a plate of iron, from its *deadening*, as it is popularly termed, the force of the blow.

76. If a series of equal spheres of some elastic substance, as ivory or steel, be suspended by threads, as ABC, &c., from the bar LM, and one of them, as A, be raised into the position K, and allowed to fall, it will strike against B with a momentum proportioned to its velocity (71), without, however, moving in any obvious manner this, or the intermediate balls. But G, the last ball in the series, will start into motion, and, all opposing forces being removed, rise to an elevation H, equal to that of K, so that the angles KLA and GMH will be equal. The ball G will then fall and strike F, and A will again be elevated, and so on, the terminal balls continuing this alternate vibrating movement as perfectly as if the intermediate balls were absent, until, from friction and other causes, they cease to move. This curious phenomenon arises from the nearly perfect elasticity of the balls, for when A strikes B, the latter becomes compressed (17), and almost instantly recovering its former figure, reacts on C; this undergoes a change in its turn, and reacts on D, &c., until the last ball G is acted on, which, having no one to oppose, obeys the force and separates from the rest, forming a determinate angle GMH.

Fig. 42.

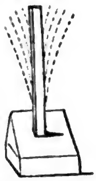


If a number of ivory balls, instead of being suspended, be placed on a table, so that their centres lie in the same right line; and one of them A, being separated from the rest, be propelled towards *a* with a certain degree of force, the terminal ball *g* will move off with a corresponding degree of momentum (all opposing forces apart); and gains the situation G, the intermediate spheres being unaffected, except in the imperceptible manner just described.

77. We have already learnt that the constituent atoms of bodies are naturally in a state of equilibrium. This state can be by means of an applied force disturbed; and if the disturbing force be not so intense as to produce disruption, the atoms soon recover their natural position. This restoration of equilibrium does not, however, occur at once and suddenly, but by a series of alternating movements, by which the atoms are approximated and separated repeatedly, until at length they attain a state of rest in their normal position. Such motions are of high importance, and are known by the names of vibrations, waves, undulations, or oscillations, according to the particular circumstances under which they are produced.

The effects of these molecular movements are readily observed by fixing

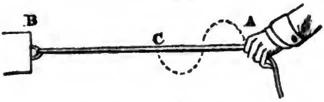
Fig. 43.



an elastic piece of steel to a support at one end, leaving the other free. The rod shown at rest is perfectly vertical; on applying force to draw it on one side, and then removing the hand, it will fly back, not to its original rectilinear position, but will go beyond this considerably, becoming curved in the opposite direction; these series of *vibrations* each decreasing in magnitude, as shown by the dotted curves in the figure, will continue for some time, and at length they will cease, and the rod once more be left in its original vertical position. A little reflection will show that, during these series of movements, the constituent atoms of the rod must have been alternately separated and approximated, according as one or other of the sides of the steel became convex or concave (12).

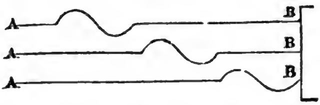
78. Vibratory motion may be successively communicated to every part of a body, or be participated in by every part at once. To illustrate the former of these conditions, fix one end of a rope to a support B, grasping the other end in the hand; on giving it a sharp jerk, the end nearest the hand will

Fig. 44.



assume the curve shown by the dotted line AC. On carefully watching the rope, this curved motion will be observed to be propagated through its whole length up to B, as shown in the following figures.

Fig. 45.



79. As soon as the vibration or wave reaches the fixed end of the rope, it is reflected back to A, so as to reach it in the opposite *phase* to that in which it left it, as shown below, in which the entire line indicates the course of the primary vibration propagated from A to B, and the dotted lines the reflected vibration from B to A. These motions ultimately cease from the influences

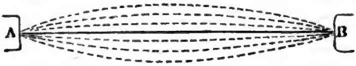
Fig. 46.

of opposing causes, and the rope obtains a state of rest. On looking intently on a rope thus moving, it is almost difficult to believe that the particles of the rope do not really move from one end to the other. A moment's reflection shows this to be impossible, and teaches us that this optical delusion (for such it is) is merely owing to a propagation of motion from one particle to another, each atom obtaining a state of rest as soon as it has given up its motion to the

atom in advance of it, in a manner analogous to the propagation of motion through a series of electric bells (76). The particular kind of vibration illustrated in the rope is termed *progressive*, because it is propagated from one end of the rope to the other, a considerable portion of it being in a state of rest whilst part only is in motion.

80. Vibrations are termed *stationary* when every part of the body assumes motion at the same time, as when a rope is fixed at AB, and being drawn at

Fig. 47.

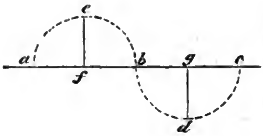


its middle from the rectilinear position, ultimately recovers it, after performing a series of vibrations in which every atom of the rope simultaneously participates.

81. One remarkable universal law governs all these movements, that no matter what their magnitude, they are always *isochronous*, that is, perform their journey on either side of the normal position of the body in equal times. In this they resemble the movements of the pendulum (104), the force of elasticity (17), however, governing the motions now under consideration, whilst that of gravity (108) regulates those of the latter.

82. In every complete vibration or entire wave, the following parts are recognized: *a*, *e*, *b*, *d*, *c*, the whole vibration or wave.

Fig. 48.

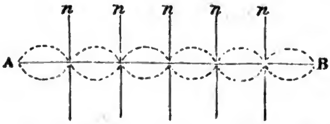


a b c the length of the wave.
a e b the phase of elevation of the wave.
b d c the phase of depression of the wave.
e f the height of the wave.
g d the depth of the wave.

Some bodies will, in consequence of their natural elasticity, readily assume these motions; others are made sufficiently elastic by artificially hardening them, as in the tempering of iron and steel; or by tension, as by stretching cords and membrane, as in the strings of a harp or the head of a drum.

83. When a body is made to assume a series of stationary vibrations (80), the points where the phases of elevation and depression intersect, are always at rest. Thus in the cord AB, which has been made to assume a series of

Fig. 49.

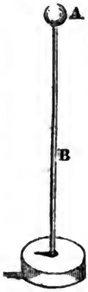


stationary vibrations, the parts marked *n* will be in a state of rest, and pieces of paper resting upon them will be undisturbed; whilst if placed on the in-

termediate portions, would be thrown off immediately. These points are called ***nodal points.*** When a plate is made to vibrate, these nodal points of rest always exist, and may be easily detected (248). The conception of the existence of such points in a plate may be facilitated by assuming it to be made up of a series of linear portions, each performing independent stationary vibrations.

84. Elastic rods or wires may easily be made to vibrate, and when uniform in structure, in equal times; the number of vibrations increase with the diminished length of the rod, in such a manner as to be performed with a rapidity inversely as the square of their length. Thus, if a rod twelve inches long perform three vibrations in a second, it will, if shortened to one-half, perform twelve vibrations, and if of but three inches in length, thirty-two in the same time.

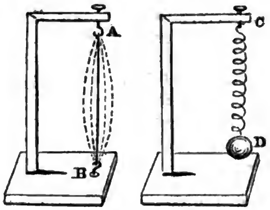
Fig. 50.



85. Rods, when vibrating, do not perform their movements in the same plane, but in paths corresponding to very complex curves. This may be beautifully seen by a contrivance of Professor Wheatstone, made by fixing a silvered glass bead, A, on the top of a steel wire, B. On making this wire vibrate, the curved path of its movements (238) will be visible by the motions of the little spot of light reflected from the surface of the head.

86. Vibrations are performed either transversely or longitudinally with regard to the axis of the body. The former may be illustrated by fixing a wire to a proper support AB, and drawing it at its middle out of its straight position; the vibrations shown by the dotted lines are *transverse* to the axis of the wire.

Fig. 51.



Fix a weight D to one end of a properly-suspended piece of brass wire CD, coiled into a loose helix. If the weight be raised to C, and then allowed to fall, it will advance and recede to and from D, the wire performing a series of longitudinal vibrations.

CHAPTER IV.

EFFECTS OF GRAVITATION.

Gravitation, 87. *Force of gravity*, 88—*motions of bodies by*, 89—94. *Opposing causes*, 95, 96. *Rotatory movement of bodies*, 97—100. *Curvilinear motion*, 101, 102. *Pendulum*, 103. *Isochronism*, 104—106—*length of*, 107—111. *Centre of oscillation*, 112. *Gridiron pendulum*, 114.

87. Among the forces which are the most energetic in producing motion on the surface of our globe is the attraction of gravitation (38); this force, whilst acting on bodies under its influence, and approaching the earth, is a uniformly accelerating force, becoming as uniformly retarding on bodies receding from the earth. So that a body acted upon by it, passes through different portions of space in different times, and, whilst approaching the earth, would each instant pass through a greater space than that which it traversed in the preceding instant of time. If a ball be let fall from the hand, it can be readily caught during the first few inches of its path, but its velocity afterwards so rapidly increases, that it cannot be incercepted by the most agile arm without difficulty. Even if the descending body fall obliquely, still the same rapid increase of velocity is perceived; this is well illustrated by the falling of bodies down steep descents, or long inclined planes; for the first few yards the mass appears to move slowly; rapidly, however, it increases in velocity, and, as well illustrated by the fall of a granite block from an alpine ridge of rock, or of the more terrific avalanche acted upon by the increasing intensity of gravitation, it acquires such a momentum (71) as to enable it to overcome the resistance of almost any obstacle it encounters.

88. A body left free to move, and acted upon directly by the force of gravitation, all opposing forces being excluded, will fall in the latitude of Greenwich at the rate of 16·0954 feet in a second of time, acquiring by this motion a velocity of 32·1908 feet, or 386·2896 inches per second. This velocity, expressed in numbers, is termed the *force of gravity*. The space traversed by a falling body in a second, is hence very nearly equal to 16 feet 1 inch; which is sufficiently correct for ordinary calculations, and to enable us to avoid decimals, which are very inconvenient, unless we use logarithms to lessen the number of figures.

89. When a body sufficiently dense and compact to permit us to disregard the opposition of the medium traversed by it, is acted on by gravitation, it is found that *the spaces described by the falling body increase as the squares of the times increase;* thus calling $16\frac{1}{12}$ feet $=f$, we find that in

2 seconds	$(2^2= 4)- 1= 3f$,	in 2d	second of time.
3	:	$(3^2= 9)- 4= 5f$,	in 3d	ditto.
4	:	$(4^2=16)- 9= 7f$,	in 4th	ditto.
5	:	$(5^2=25)-16= 9f$,	in 5th	ditto.
6	:	$(6^2=36)-25=11f$,	in 6th	ditto.

Therefore in 1, 2, 3, 4, 5, &c. seconds, the spaces traversed by a falling body are equal to f, $\times$ the odd numbers 3, 5, 7, 9, &c., respectively.

Thus, by knowing the time occupied by the falling of any dense body of small bulk, the space traversed by it can be readily calculated. If a bullet falling from a certain height reaches the earth in 3 seconds, we know that

in 1 second it traversed		16 ft.	1 in.
—2 seconds	..	$16 \cdot 1 \times 3 = 48$	3
—3 seconds	..	$16 \cdot 1 \times 5 = 80$	5
		144	9;

consequently the space traversed by it, is equal to 144 feet 9 inches. This and similar questions can be more readily determined by means of the formulæ for uniformly accelerated motion.

$$s = \frac{gt^2}{2}$$

g being equal to 32·1998 feet (88).

As an example of this formula, suppose we wish to know the space passed through by a body occupying 23 seconds in its descent, then by logarithms.

$$\begin{aligned} \log.\ 23^2 &= 2 \cdot 72346 \\ \log.\ g &= 1.50773 \\ \hline &\ \ 4 \cdot 23119 \\ \log.\ 2 &= \ \ \cdot 30103 \\ \hline &\ \ 3 \cdot 93016 \end{aligned}$$

which is the logarithm of 8514·6 feet, the space traversed in 23″ by the body.

90. A still simpler formula may be adopted, and the calculations more easily effected, by squaring the time in which the falling body passes through any space, and multiplying this product by the space passed through in a second of time. This formula expressed algebraically, calling the space passed through in a second or $16\frac{1}{12}$ ft. $= f$, is ft^2; this, applied to the last question of a body occupying 23 seconds in its descent, is

$$23 \times 23 \times 529, \text{ and } 529 \times 16 \cdot 0954 = 8514 \cdot 4666 \text{ feet;}$$

or by logarithms,

$$\begin{aligned} \log.\ \ 23 \times 23 &= 2 \cdot 72346 \\ \log. f \text{ or } 16.0954 &= 1 \cdot 20670 \\ \hline & \ \ 3 \cdot 93016 \text{ equal to } 8514 \cdot 6 \text{ feet.} \end{aligned}$$

In this manner the height of any lofty building or depth of a well or shaft may be determined; for by letting fall a pebble from the top of the one, or into the mouth of the other, and noting the number of seconds which elapse before the sound of its striking the ground or water is heard; then—on squaring this number of seconds, and multiplying the product by $16\frac{1}{12}$ feet, or, more accurately, by 16·0954 feet, the height of the building or distance of the water from the mouth of the well may be discovered. This process is of course open to the error arising from the time required for the sound produced by the pebble striking against the ground or water to reach the ear (116); and consequently the calculated length of the path of the pebble will be somewhat greater than the truth.

91. Also, knowing the time required for the fall of any body through a given space, we can readily discover the velocity with which it moves; and by knowing its velocity, we can of course ascertain the time required for its fall through any given space. The following three formulæ will be sufficient to answer every question connected with this subject; v being the velocity of the falling body, t the time of its descent, g the velocity acquired by the body after moving for a second of time, and s the space passed through in the time t (88).

$$s = \frac{gt^2}{1} \qquad v = 2gt \qquad t = \frac{v}{1g}.$$

92. When a body is acted upon by some projectile force independently of the attraction of gravitation, the motion it assumes is a compound one, produced under the combined influence of the projectile force, a momentary one, and the gravitative force which is permanent. If a body, instead of being acted upon by gravitation alone, be forcibly *projected* downwards with a given velocity per second; this is to be taken into account, and being expressed in feet, and multiplied by the number of seconds, the product is to be *added* to the space, also expressed in feet, which the body would have traversed in the same time, if acted upon by the force of gravitation alone. If, on the contrary, the body be projected perpendicularly upwards, its course being opposed to the attraction of gravitation, instead of being *added*, the effect of the latter is to be subtracted from the space passed through by the projectile, if acted upon by the force of projection only. The following examples will illustrate these remarks:

(A.) To what height will a body rise in 3 seconds if projected upwards with a velocity of 1000 feet per second?

The space described by a force of projection only will be $100 \times 3 = 300$
Space through which the body would fall if acted upon
by gravitation alone during that time (89) $= 144{\cdot}75$

$155{\cdot}25$

And the height attained will be but 155·25 feet.

(B.) Where will a body, projected perpendicularly upwards, with a volocity of 80 feet per second, be in 6 seconds?

By force of projection alone, $80 \times 6 = 480$
.. gravitation alone, $16{\cdot}0954 \times 36 = 579{\cdot}4344$, and $480 - 579{\cdot}4344$, $= -99{\cdot}4344$.

The body will therefore be nearly 99·5 feet lower at the end of 6 seconds, than the spot from whence it was first projected; providing no mechanical obstacle be present to prevent this taking place.

(C.) What space will a body pass through in 4 seconds, if projected vertically downwards with a velocity of 30 feet per second?

Then by force of projection alone, $30 \times 4 = 120$
.. gravitation alone, $16{\cdot}0954 \times 16 = 257{\cdot}5264$ and $257{\cdot}5264 + 120 = 377{\cdot}5264$ feet.

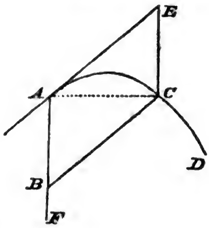
The body will consequently pass through rather more than 377·5 feet in four seconds.

93. If a body be projected in any other direction than vertically upwards or downwards, and consequently in a course oblique to that of gravitation, it will not follow the exact direction of either of these forces, but will take a resultant course proportioned to both the forces (63). This result can never be a right line, as it will vary every instant on account of the unequal intensity of the earth's attraction at different distances, consequently the path described by the body will be the curve called the parabola. If a body be projected exactly horizontally, it will describe half a parabola, its vertex exactly corresponding to the point of projection. The position of this vertex varying according to the direction of projection from a horizontal line.

When bodies move with considerable velocities through the air, the resistance of this medium interferes in an astonishing manner with the regularity of the parabolic path, which would otherwise be described by the projectile. Thus a 24-pound shot discharged at an elevation of 45° with a velocity of 2,000 feet per second, would in vacuo reach the horizontal distance of 125,000

feet, but the resistance of the air limits its range to 7,300 feet. Thus let a body placed at A be projected in the direction AE. Draw AB perpendicular to the horizon; then let AE be the space over which the velocity of projection will carry the body in a given space of time, and AB the distance it would traverse in the same time when acted upon by gravitation alone; now draw BC parallel to AE, and EC to AB completing the parallelogram (63). Then, in consequence of the opposed action of these two forces, the body will be found at the end of the given time at C instead of E, having described the parabolic curve AC, which is the resultant of the two forces (64) of projection AE and of gravitation AB. The line AE, representing the direction in which the force of projection alone would have carried the body, is a tangent to this parabolic curve, being parallel to the ordinate BC.

Fig. 52.



A bullet projected from a gun, a ball from the hand, the stone from a sling, the arrow from a bow, &c., all describe parabolic curves when projected under the conditions already referred to, being ultimately brought to the ground by the all-powerful force of gravitation.

94. If a body, instead of moving freely, be made to roll down an inclined plane, free from friction, the same laws of acceleration of motion are observed with regard to the vertical distance passed through, as with bodies falling perpendicularly: the velocity acquired in falling down the length, AB, of an inclined plane is equal to the velocity it would acquire by falling down its perpendicular height, AC. The velocity acquired in falling down the whole length, AB, varies as the square root of the perpendicular height, AC (132).

Fig. 53.

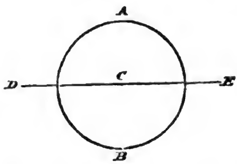
95. In all these observations, the resistance of the medium in which the body under consideration moves, as well as the interference produced by friction, have been neglected; they furnish, however, very important sources of opposition to the regularity of motion. *Cæteris paribus*, the denser the medium, the greater the opposition to the passage of the body moving through it; and in the same medium the resistance opposed to the movement of the body, is proportioned to the square of its velocity. It has been demonstrated by Sir Isaac Newton, that, when a spherical body moves in a medium at rest, of equal density to itself, it loses half its motion before it has described a space equal in length to twice its diameter. This resistance is a consequence of the molecular inertia of the medium, preventing the particles opposed to the moving body acquiring instantaneously a degree of movement corresponding to that of the body. The atmospheric resistance (42) is sufficient to prevent projectiles (93) describing a strictly accurate parabolic curve, as required by the theoretical considerations, and limits the path of the moving body to a remarkable degree. According to Vega, it appears that a cannon-ball weighing four pounds, and which *in vacuo* would traverse 23,226 feet, will, when passing through the air, travel through but 6,437 feet.

96. In all cases in which one body moves on the surface of another, a considerable resistance is generated to its free motion, and to this the term *friction* is applied. This resistance is diminished by making the points of contact of the two bodies as small as possible, by carefully smoothing their surfaces, or by the use of some unguent or greasy matter. As a rule, the amount of re-

sistance from friction is generally proportional to the pressure exerted upon the moving body. Thus, a flat piece of cast iron, having a surface of 44 square inches, was placed upon a larger piece, and so loaded as to weigh 24 pounds. A force of 51 ounces being applied, was found just sufficient to cause it to slide on the surface of the larger piece; the weight being increased to 48 pounds, a force of 104 ounces was required to move the loaded piece of iron. The result of experiment thus very slightly differed from the theoretical law, that friction is proportionate to the pressure.

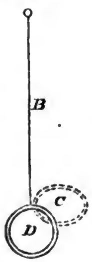
With equal surfaces and pressure, friction increases in the direct ratio of the extent of surface, and the rougher the surfaces the greater the friction. Mr. Babbage found that a rough block of stone weighing 1080 pounds, required a force of 758 pounds to move it on the surface of the rock from which it was hewn. Placed on a wooden sledge on a wooden floor, a force of 606 pounds was sufficient to draw it along. When the floor and bottom of the sledge were covered with tallow, a force of 182 pounds was sufficient, and lastly, when allowed to rest on wooden rollers three inches in diameter, it could be easily moved by a force of only 28 pounds.

Fig. 54.



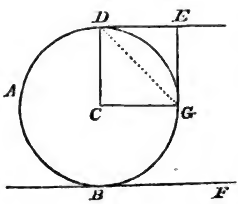
97. If a spherical body AB, receive an impulse in the direction of a line DCE, passing through its centre of gravity (46) C, all its parts will move with equal velocity in a straight line. But if the force applied does not act on the centre of gravity, the particles of the body will possess unequal velocities, and the whole mass will require a revolving or rotatory motion, at the same time that it moves onwards under the influence of the applied force. Thus, the earth is a body which revolves on its own axis, at the same time that it moves through space; and if this motion has been acquired from a single impulse, it must have been exerted upon a point situated about 25 miles from its geometric centre.

Fig. 55.



98. Almost all moving bodies present this peculiar rotatory motion whilst passing through the air, on account of the force acting upon them having been exerted on some point excentric to their centres of gravity. Where the bodies are not spherical, they always rotate round their shortest axis. This may be illustrated by suspending a metallic ring D to a thread B. If this be rapidly rotated by twisting the thread between the fingers, the little system will tend to rotate round the shortest possible axis; to effect which the ring D alters the direction of its motion and attains that shown by the dotted curve C, the diameter of which is at right angles to the position of the string which supports it.

Fig. 56.



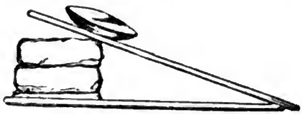
99. If the body be of sufficiently regular form, and propelled along the ground, it revolves round its horizontal axis, even if the applied force has acted directly upon its centre of gravity (97).

Let the ball ADGB be projected along the plane BF, with a certain degree of force applied in the direction of a line passing through the centre of gravity C. This force will act equally on every molecule of the ball, but the friction against the plane at B will prevent its

moving with facility, whilst the opposite point D, being free from this opposing force (95), will tend to move on with all the force which projected the ball. As D cannot separate from B, it may be supposed to possess, for an instant only, a degree of velocity greater (because unopposed) than B. Draw DC perpendicular to B, to represent the force of friction at B, and DE parallel to BF, to represent the direction of the force of projection, complete the parallelogram (92) by drawing EG and CG parallel respectively to DC, DE, and draw the diagonal DG, which will be the resultant line of direction. Accordingly, the point D will pass down to G, causing the ball to revolve one quarter of the circle: another portion A coming to D, the same state of things occurs, producing the rapid rotation of the ball round its horizontal axis.

100. If the body be so situated as to have capillary or cohesive attraction (22, 24), acting as the opposing force, rotation round a vertical axis takes place, providing the body be of convenient form. This is shown by placing a watch-glass, or plano-convex lens, on a smooth inclined plane, as a pane of glass; having previously dipped the convexity of the watch-glass in water. Thus arranged, the glass, on sliding down the plane, will rapidly revolve round a vertical axis; whereas, if the plane and glass be perfectly dry, it will slide down and reach the bottom of the inclined plane without revolving. This rotating motion is explained by the adhesion produced by the drop of water causing the portion of the watch-glass immediately below its centre to approach close to the plate. The centre of gravity of the watch-glass becomes slightly elevated, and for the want of support must fall (48), and thus commences the rotation which continues from the same cause until the moving body reaches the bottom of the inclined plane.

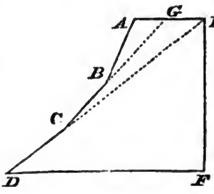
Fig. 57.



101. When a body unopposed by friction, or resistance of the air, descends a series of super-posed inclined planes, the velocity acquired by it is equal to that which would be acquired in falling through the vertical height of the series, as in the case of a single plane (94).

Let ABC represent the planes, and let C and B be produced until they meet AE in G, E. The velocity acquired by a body falling from A to B is equal to that which it would acquire in falling from G to B, for the planes AB GB have the same perpendicular height; and when this is the case with any two planes, the velocities acquired in falling down their whole lengths are equal (94). The body having reached B will descend BC with the same velocity, whether it fall down AB or BG; then the velocity acquired at C will be the same, whether the body fall down GBC or EC; and finally, it will pass down to D with the same velocity as if it had rolled directly from E. The same reasoning will apply to bodies falling down curves, for their figures may be considered as made up of an infinite series of planes.

Fig. 58.



102. All bodies free from obstacles will have their motion as much accelerated, whilst descending, as retarded whilst ascending, a curve. Let CAB (fig. 59) be a curve, and a ball be placed at C, the attraction of gravitation will cause it to descend to A; in this motion it will acquire a degree of momentum (71)

Fig. 59.

sufficient to carry it onwards to B, gravitation will once more pull it down to A, and the momentum thus generated will carry it onwards to C; it will again fall to A, and so on, oscillating from C to B, until opposing causes bring it to a state of rest. The whole time of ascent to B or C will be equal to the time of descent to A, as the velocities at equal altitudes are equal.

103. For the purpose of causing the body to move in a curved path with as little friction as possible, it may be fixed to a suspended wire or string, and then permitted to oscillate; an instrument thus constructed is termed a *pendulum.* This, theoretically considered, consists of a ball suspended to a thread, unacted upon by any opposing or resisting forces. If the ball C (fig. 60) be raised to A, and allowed to fall, it passes through C to B in the manner already described; the whole movement of the ball from A to B, or B to A, is termed *an oscillation;* from A to C, its movement is termed the descending, and from

Fig. 60.

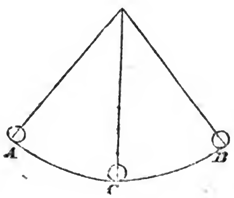
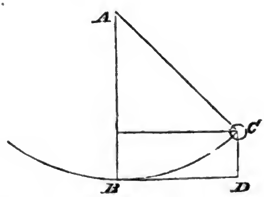


Fig. 61.



C to B its ascending, *semi-oscillation.* The distance AB, measured in degrees, is termed the *amplitude* of an oscillation; and the *duration* of an oscillation is the time required to effect this movement from A to B, and vice versâ. The path described by the oscillation of a pendulum is the necessary consequence of gravitation, and explicable on the doctrine of resolution of forces (66). For let the pendulum AB (fig. 61) be elevated to C, and then left free to move, it will be acted upon by the force of gravitation, and, describing the curve CB, reach B; this line may be considered as the resultant of two forces, one acting in the direction CD, and the other in the direction BD.

104. The duration of an oscillation is independent of its amplitude; and upon this depends the isochronous property of the pendulum; for the same time is required in a pendulum of given length to oscillate through 0·1° as through 10°, although the amplitude of oscillation in the latter is 100 times greater than that in the former. This fact depends upon the ball, in falling through 10 degrees, acquiring a considerable momentum, and, consequently, moving with greater velocity than if it had traversed a less number of degrees, is thus enabled to traverse a longer path in a comparatively shorter time. The oscillations of the pendulum are, however, only isochronous when the curve in which they move is a cycloid, a curve generated by the rotation of a wheel on a plane surface. The base of the cycloid being equal to the circumference of the circle whose rotation generated the curve, the area of which is always triple that of the generating circle.

105. The duration of oscillations does not depend upon the nature of the substance composing the pendulum, and is always in the ratio of the square roots of the lengths of the thread or wire of the pendulum. Thus, if a pendulum of a given length perform one oscillation in a second, it requires one

the square of that length to perform an oscillation in double, and the square root of the length to perform it in half that time.

The duration of an oscillation being as the whole numbers	1	2	3	4	5	6	7	8	9, &c.
The length of the pendulum will be as the squares	1	4	9	16	25	36	49	65	81, &c

106. If a pendulum be made to vibrate in considerable arcs, an exception to the law of isochronism is observed, an addition of a minute portion of time being required to complete oscillations of considerable amplitude, as compared to those of lesser arcs. This circumstance is explained by the fact that a body suspended to a string must vibrate really in arcs of a circle of which the centre is the point of support. As the curve surface of a cycloid and circle coincide exactly through only a very small arc, it follows that if the ball of the pendulum oscillates beyond the limits of this arc, it no longer moves in a cycloidal path, and its vibrations lose their strictly isochronous character. If we take unity for the time of an oscillation through an infinitely small arc, the excess of time required to complete larger oscillations will be

For an arc of 36°, 0·01675
15°, 0·00426
10°, 0·00190
5°, 0·00012
2°, 0·00003

107. As the movements of the pendulum depend upon gravitation, and as this force decreases in intensity as we recede from the earth's centre, (45,) this instrument affords a most valuable mode of determining the intensity of gravity, and, consequently, the distance of the surface of the earth from the centre, in different parts of the globe. This is done either by ascertaining the time required to complete an oscillation of a standard pendulum: or, the length of a pendulum, requisite to complete an oscillation in a given time. The length of a pendulum required to vibrate seconds in the latitude of Greenwich is 39·1393 inches, and, consequently, one requiring two seconds to complete a vibration, will measure 156·5572 inches, or rather more than 13 feet, whilst one vibrating but half seconds will measure but 9.784895 inches, or rather more than $9\frac{3}{4}$ inches.

108. The intensity of gravitation, or force of gravity, (88,) (expressed by the number of feet, showing the velocity acquired by a dense body after falling for an entire second,) in any part of the world, is found by multiplying, by the length of the pendulum beating seconds, the number, expressing the ratio of circumference to diameter, of a circle whose radius is 0·5; and dividing the product by the square of the duration of an oscillation. This calculation is better expressed thus:

l = length of pendulum in inches;
t = time required for completing an oscillation in seconds;
π = the ratio of circumference to diameter, or 3·1415927;
g = the intensity of gravitation as above explained:

then the formulæ for the pendulum will be

$$t = \pi \sqrt{\frac{l}{g}}, \text{ and consequently } g = \frac{\pi^2\, l}{t^2}$$

As an example of the use of this formula, let us suppose that the force of gravity, or velocity acquired by a body falling freely during one second of time in England, is required; then, by logarithms,

8*

$$\begin{aligned} \log. \pi^2 &= 0\cdot99430 \\ \log. (l = 39{,}1393) &= 1\cdot59261 \\ \hline & 2\cdot58691 \end{aligned}$$

corresponding to 386·29 inches, or, more accurately. 386·2894, as before stated (88.) Again, suppose the same question has to be determined with regard to Sierra Leone; at this place Colonel Sabine has determined the value of l, or length of pendulum beating seconds, to be 39·01954 inches, consequently,

$$\begin{aligned} \log. \pi^2 &= 0\cdot99430 \\ \log. \ l &= 1\cdot59128 \\ \hline & 2\cdot58558 \end{aligned}$$

corresponding very nearly to 385·10 inches, which will be the velocity acquired by a body falling freely during one second, at Sierra Leone.

109. These computations may be made still more readily by multiplying the exact length of a pendulum vibrating seconds at any given place by the number 9·8696. Thus the force of gravity at Greenwich may be calculated by multiplying the length of the second's pendulum, or 39·139 by 9·8696 = 386·289 inches. A pendulum vibrating seconds must be a little more than one-fifth of an inch longer at the poles than at the equator.

110. The following are the results of some measurements of the seconds' pendulum, at different parts of the world:

Place.	Latitude.	Value of l, or length of pendulum.	Observers.
Spitzbergen . .	76° 49′ 58″ N.	39·21464	Col. Sabine.
Leith	55° 58′ 41″ N.	39·15540	Capt. Kater.
London	51° 31′ 08″ N.	39·13908	Do.
Jamaica	17° 56′ 07″ N.	39·03508	Col. Sabine.
Ascension . . .	7° 65′ 48″ S.	39·02406	Do.
Sierra Leone . .	8° 29′ 28″ N.	39·01954	Do.

By observations and calculations of this kind, the flattening of the earth at the poles and bulging out at the equator, have been most accurately determined (59).

111. To determine the time required for a pendulum of any given length to complete an oscillation in the latitude of London, it is only necessary to take the square root of the length of the pendulum computed in feet, and to multiply this result by the decimal 0.55372. Thus, if the pendulum were nine feet in length, it would perform an oscillation in 1·66 seconds, for—

$$\sqrt{9} \times 0.55372 = 1\cdot66116.$$

To ascertain the length of a pendulum which is required to perform a vibration in a given time, in this country, we have only to multiply the square of the number of seconds by the number 3 2616, and the product will be the required length in feet. Thus, if it be required to discover what length a pendulum must possess to beat double seconds—

$$2^2 \times 3{\cdot}2616 = 13{\cdot}0464 \text{ feet.}$$

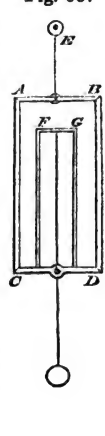
112. In the theoretical considerations and formulæ above mentioned, we have considered only the simple pendulum, or one whose wire is absolutely without weight; a condition of course physically impossible. Some slight reservation must, on this account, be made in applying to practice the formulæ of the pendulum. If a pendulum be suspended by means of a knife-edge, and unopposed by the resistance of the atmospheric air, it will continue oscillating for several hours, describing equal arcs in equal times, until it gradually comes to rest. As, however the wire supporting the ball is never destitute of weight, there are some opposing causes to its completing an oscillation in a theoretically correct period, which must be noticed. If the pendulum AD be allowed to oscillate, and the wire be without weight, the duration of its oscillations will be consistent with theory; but as the wire is ponderable, every atom of it has a tendency to complete the oscillation in a less time than the molecule beneath it, for if the pendulum be only as long as AB or AC, it will of course complete its vibrations in much less time than if as long as AD. Accordingly, every portion of wire will tend to complete its oscillations in different times, and these actions will, to a certain extent, oppose each other. At a certain point in the pendulum these actions will be mutually neutralized, and this is termed the *centre of oscillation*. This point can, practically, be brought very low into the ball of the pendulum; and is effected by making the ball very heavy in comparison with the wire to which it is attached. The length of a compound, or ordinary pendulum, is the distance from this centre to the point of suspension.

Fig. 62.

113. The centre of oscillation is the same with the *centre of percussion*, or that point where all the percutient force of a rod or bar is concentrated. This differs materially from the centre of gravity, for on striking anything with a stick at its middle point, it is well known that the whole force of the blow will be much less than if the body be struck with that portion of the stick which is further from the hand.

114. As all bodies are acted upon by changes of temperature, so that their length becomes altered, it is of extreme importance to have a pendulum constructed in such a manner, as to be unaffected by such changes. Several modes have been proposed to effect so desirable an object; none, however, are more effectual than the well-known gridiron, or compensating pendulum, composed of two or more metals, so arranged that the expansion of the one counterbalances that of the other. In the simplest possible form, this contrivance consists of a parallelogram of steel, ABCD, fixed to the rod E, by which the whole pendulum is suspended. The copper rod FG, bent twice at right angles, is fixed by its lower ends to the transverse piece CD, and from the upper part of FG, the rod supporting the ball of the pendulum is affixed. It is obvious, that as copper dilates much more than steel by equal elevations of temperature, in the proportion of 1·00191880 to 1·00118980, if the size of the steel and copper bar be properly adjusted, any elevation of temperature which, by expanding the steel bar, would increase the length of the pendulum, will be completely counteracted, by the expansion of the copper bar in the opposite direction. The importance of an arrangement of this kind is sufficiently obvious, as an alteration of 30° of temperature, by affecting the length of a pendulum, would introduce an error of 8 seconds in 24 hours. In all observations with pendulums requiring great accuracy, the

Fig. 63.



lateral attraction of mountains and elevated buildings (40), as opposing the attraction of the earth, must be carefully borne in mind, otherwise errors of great importance will be introduced into our calculations.

CHAPTER V.

OF THE MECHANICAL POWERS, OR SIMPLE MACHINES.

Exchange of Time for Power, 115. *Centre of Parallel Forces*, 116. *Theory of Lever and Balance*, 117. *Weighing with False Balances*, 119. *Momentum of Long Arms of Levers in Action*, 120. *Archimedes' Problem*, 121. *Kinds of Levers*, 122. *Conditions of Equilibrium in the Lever*, 125. *Wheel and Axle*, 126. *Pulley*, 127. *Compound, or Systems of, Pulleys*, 129. *Angular Divergence of Cords of Pulleys*, 131. *Inclined Plane*, 132. *Theory of*, 133. *Screw*, 134. *Wedge*, 135, 136. *Levers in the Animal Structures*, 138, 139. *Pulleys in*, 140. *Wedges in*, 141.

115. The mechanical powers furnish the most simple instruments that can be employed for the purpose of raising or supporting weights, or communicating motion to bodies; and all machines, complicated as they are, with which the ingenuity of man has furnished us, are nothing more than combinations of these simple powers. By means of these simple machines, it must not be supposed that we beget or increase force; all that we do, is to apply force in a convenient and economic manner. Thus, if a man could raise to a certain height 200 pounds in one minute, with the utmost exertion of his strength, no power could enable him to raise 2,000 in the same space of time. If left to elevate the mass by his own unaided strength, he would be obliged to divide the mass into ten different portions, and raise each separately, whereas, by means of one of the simple machines, he will be enabled to raise the entire mass at once, requiring, however, for the performance of the task, ten times the number of minutes in which he raised the 200 pounds.

Thus it is, *in limine*, obvious that we exchange time for power in using simple machines; and this is true with all the varieties of apparatus to which that term has been applied. The simple machines may be divided into three species:

1. The lever,
2. The pulley,
3. The inclined plane;

the theoretical properties and peculiarities of which, with their chief modifications, we shall now briefly describe.

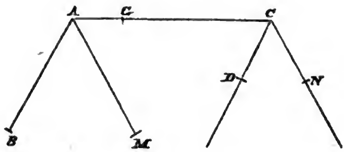
1. THE LEVER.

116. The lever, theoretically considered, is an inflexible rod, destitute of weight, perfectly straight, and moving without friction on a fulcrum or support, corresponding to the centre of motion.

Referring to what has been already stated with regard to the centre of parallel forces (46), we find that, whenever a series of forces, perfectly parallel in direction, act upon a mass, they may be replaced by one force, which

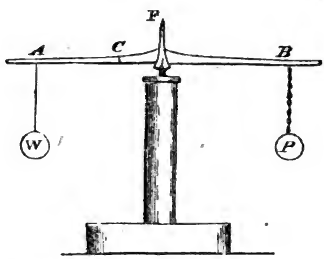
may be considered as their centre, or resultant. The following are the chief properties of this resultant. A. It is equal to the *sum* of the forces if they are all exerted in one direction, and to their difference if exerted in opposite directions. B. It is parallel to the forces of which it is the resultant. C. It is placed at a certain point G, in such a manner that the distances GC, GA, are in the inverse ratio of the forces CD and AB, which are supposed to be acting

Fig. 64.



on the extremities AC of the bar AGC. This point remains the same when the forces change their absolute directions, providing they remain parallel; for if the above forces act in the direction CN, AM, instead of CD, AB, the centre will still be G, because they have not changed their intensity, and their power is in the inverse ratio of GC, GA.

Fig. 65.

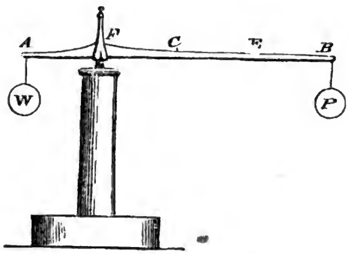


117. Let the inflexible bar AB be balanced on a fulcrum at its centre of gravity, it will, of course, remain in perfect equilibrium. Suspend from the end A a weight W; immediately this mass is added, the centre of gravity will no longer be over the fulcrum but nearer the end A, and this point, being unsupported, will be drawn down by the attraction of the earth, consequently equilibrium will be destroyed. Then suspend from the end B a similar weight P; the centre of gravity of the whole, as the bar and the weight may be considered as forming one mass, will be once more over the fulcrum, and the whole will be supported in equilibrio. If, instead of P being equal to W, it be one-fourth less, then the centre of gravity will be no longer over the fulcrum, but nearer A, as at C, and the gravitative attraction of the earth drawing this point down, will cause W to preponderate; nor can the state of equilibrium be obtained, unless weights be added to P, until it becomes equal to W. This form of lever is evidently nothing more than the ordinary balance; and we find that when the weights PW are equal, the length of the lever on

both sides of F must be equal. These portions FA FB are termed the arms of the lever.

118. If the weights PW remain equal, but the position of the fulcrum is changed to F, then equilibrium will no longer occur, for the arm FB will preponderate; this necessarily occurs, for the centre of gravity C, being no longer supported, the force of gravitation draws it towards the earth. But let AB be

Fig. 66.



graduated into four equal portions, AF, FC, CE, EB, and let the point F be supported: it is obvious that things remaining as they were, a state of equilibrium can only be obtained by throwing the centre of gravity over the point of support, or fulcrum. This may be effected by diminishing the weight P; and if this be done gradually, the centre of gravity will be found to approach towards F in proportion as we diminish P; and when this is equal to one-third of W, the centre of gravity will be exactly over the fulcrum, and equilibrium obtained. Now, as P is equal to 1, and W equal to 3, whilst the arm to which P is attached, is thrice as long as that to which W is suspended, we deduce the general law that *the power P and weight W are always in equilibrio, when they are to each other in the inverse ratio of the arms of the lever, to which they are attached.* Consequently, any weights will keep each other in equilibrio, on the arms of a straight lever, when the products arising from multiplying each weight by its distance from the fulcrum, are equal on each side of the fulcrum; and, as in the above example, $P = 1$ and $W = 3$; whilst $AF = 1$ and $FB = 3$, it follows that $(W \times AF) = (P \times FB)$ and both being equal to 3, equilibrium necessarily results. Of the lever with unequal arms, the common steelyard, used for weighing heavy weights, is a good example.

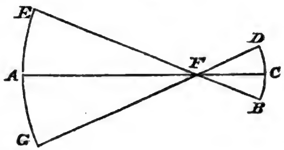
119. As a smaller weight is made to counterbalance a greater, by lengthening one of the arms of the lever when arranged as a balance, it frequently tempts the dishonest vender to thus alter his scales, to cheat the unsuspicious buyer; of course this is readily detected, by weighing the substance to be purchased first in one scale-pan, and then in the other. If the balance be correct, it will weigh the same in both; but if incorrect, its apparent weight will be different in each scale pan. To determine the true weight of a substance with such a balance, weigh it first in one scale-pan, then in the other; multiply these two weights together, and take the square root of the product. Thus if a substance weighed 253 pounds in one scale and 251 in the other, $\sqrt{251 \times 253} = 252$ pounds, the true weight.

Another process for weighing accurately with a false balance has been devised by Borda, which, indeed, furnishes us with the most accurate mode of ascertaining the exact weight of any substance, even with a good balance. For this purpose, accurately counterbalance the body to be weighed by means

of any heavy substance, as fine leaden shot or sand. Then remove the body and replace it by weights carefully introduced into the scale-pan, until the shot or sand be counterbalanced, and the equilibrium restored. These weights will give the true weight of the body free from any error arising from imperfections in the balance.

120. In the lever with unequal arms, it is obvious that the velocity with which its extremities move is very different. Let the line AFC represent a lever, turning on the fulcrum at F as on a centre, and suppose a weight to be attached to the end C, and a force applied to A sufficient to move it.

Fig. 67.



Then, while the end C describes the arc DCB, the force applied will pass through the arc EAG, the length of each arc being in the inverse ratio of the force applied to each, and in the direct ratio of the arms of the lever. We see, also, that a small weight attached to A, and passing through the space EAG, will, by its velocity, generate a degree of momentum (71) sufficient to overcome the resistance afforded by a much heavier weight attached to C, moving, as the latter necessarily must, with less velocity. For, as from the conditions of this lever, the arcs BD EG must be described in equal times, and as EG is much larger than DB, it follows that the end A must move with as much greater velocity than C as the arc EG is larger than DB. As the momentum of a body is equal to its quantity of matter, multiplied by its velocity or quantity of motion, we learn that equilibrium must occur in a lever, when the weights at either end, multiplied by the velocities with which they move, are equal to each other. From this reasoning, we also become convinced of the truth of the statement we set out with, that the application of the mechanical powers is an exchange of time for power (115).

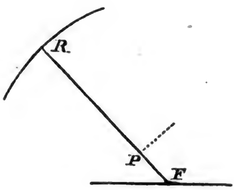
121. The difference in the velocity of the unequal arms of a lever, and consequently of the time required by the ends of each to traverse a given space, is well illustrated by the solution of the celebrated case assumed by Archimedes of Syracuse. This philosopher, seeing the immense power capable of being exerted by a lever, declared that if he had a place to stand on, and were provided with a sufficiently long lever, he would move the world. If it be granted that he could exert a force of 30 pounds in pulling an arm of a lever through 10,000 feet per hour, he would, to raise the earth a single inch, have to cause the end of the long arm of a lever to pass through an arc which would require the continued labor of 8,774,994,580,737 centuries to accomplish, supposing Archimedes worked for 8 or 10 hours per day.

122. The levers just described have been termed levers of the first class, and are characterized by having the fulcrum at some point between the power applied, and the resistance to be overcome. Those levers in which the fulcrum is applied at one end, and the resistance at an intermediate point, have been termed levers of the second class; whilst those in which the power is applied between the fulcrum and resistance, are placed in a third class. The only real distinction that it is necessary to make, is between levers in

which the fulcrum is between the force applied and the resistance, and those in which the fulcrum is at one end. The proportion between the forces to produce equilibrium is expressed in the same terms in each case, the great difference between them being that, when the fulcrum is central, as in the lever already adverted to, the pressure upon it is equal to the *sum* of the forces applied, and to their *difference*, when the fulcrum is terminal.

123. That modification of the lever in which the force is applied between the fulcrum and resistance, is not very frequently met with; indeed, on account of the mechanical disadvantage in which the force is necessarily exerted, it is never used except to gain considerable velocity. If RPF represent such a lever moving on a hinge as a fulcrum at F, and force be applied at P, it is obvious that whilst P moves through a small arc, R will describe a very large one; and as both are performed in equal times, the velocity of the end R is considerably greater than the end near F. The treddle of a lathe, and the common tongs, used to supply the fire with fuel, afford an example of this kind of lever; the sheep-shears, sugar-tongs, &c., are similar examples.

Fig. 68.



124. Of the first described lever, in which the fulcrum is central, examples are met with in the crow-bar, scissors, forceps, pincers; and in the ordinary poker, when it rests on the bar, in the act of stirring the fire, &c. Of the second kind of lever, in which the fulcrum and power applied are both terminal, an oar will afford an example, the water being the fulcrum, the boat the resistance, and the hand of the rower the power. The chipping knife used by druggists, in which the end is fixed to a board, the common nutcrackers, and the chaff-cutter, are also instances of this kind of lever.

In the following figures of the crow-bar, chipping-knife, and treddle of a lathe, affording examples of the three forms of lever, the letters PFR respectively point out the position of the power, fulcrum, and resistance.

Fig. 69.

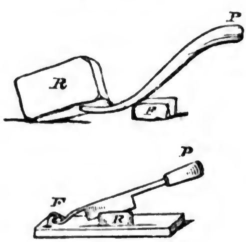
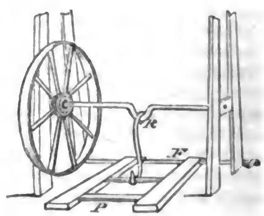


Fig. 70.



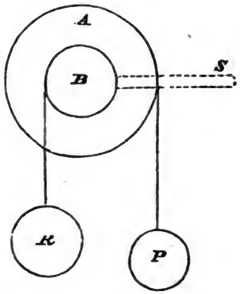
125. As a general statement of the necessary conditions for obtaining equilibrium with the lever, the following formula, in which $R =$ resistance to be moved. $P =$ power applied, $p =$ the arm to which P is affixed, and $r =$ that connected with R, may be useful:

$$P : R :: r : p, \quad \text{and } P \times p = R \times r \text{ (118).}$$

Simple levers are sometimes so combined, that instead of acting directly on the resistance, they act on a second lever, and this sometimes on a third, which then exerts their combined effect upon the resistance. Some varieties of cutting bone forceps are constructed in this manner. The patent weighing-machine is a combination of levers, arranged at right angles to each other.

126. The wheel and axle is a modification of the lever, in which considerable mechanical advantages are gained. This machine consists of a cylinder B, termed the axle, turning on a centre, and connected with a larger circle of wood or other substance, A, called the wheel. Sometimes this is replaced by a spoke, as S, fixed into B, to the end of which the force is applied. The resistance to be overcome is fixed to one end of a rope wound round the small cylinder B, whilst the power is applied to the circumference of A, generally by means of a rope, P, acting in the direction of a tangent to A. Here the radius of the smaller circle or axle may be considered as corresponding to the short arm, and the radius of the larger or wheel, or the length of the spoke fixed into A, to the longer arm of a straight lever. And accordingly we find that equilibrium is obtained when the power applied, is to the resistance to be overcome, in the same ratio as the radius of the smaller cylinder, or axle, is to that of the larger, or wheel. Calling the radius of the wheel W, and that of the axle w,

Fig, 71.



$$P \times W = R \times w.$$

The winch, windlass, capstan, crane, afford examples of the practical application of this useful modification of lever. In the following figures representing several varieties of the wheel and axle, the same letters of reference are used as in the diagram last described.

Fig. 72.

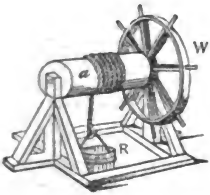


Fig. 73.

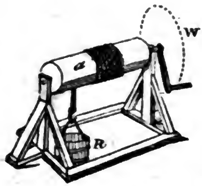
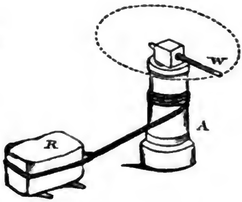


Fig. 74.



2. PULLEY.

127. The simplest form of pulley consists merely of a ring or groove in a beam, used only to change the direction of motion. As usually constructed, it is a small wheel movable about its centre, in the circumference of which a groove is formed to admit a rope or flexible chain.

9

In the single fixed pulley movable round its centre, C, no increase of power is gained, but merely a convenient mode of applying force. For if the perfectly flexible rope AB be passed over the pulley, equilibrium will occur when the weights RP are equal; both containing equal quantities of matter, will be equally acted on by gravitation, and be necessarily in equilibrio.

Fig. 75.

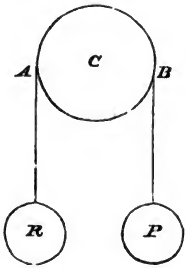
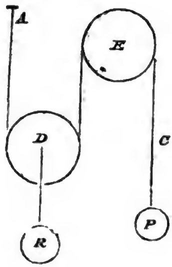
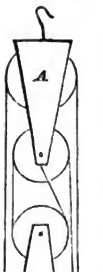


Fig. 76.



128. If we use a movable pulley we become enabled to raise a resistance of 2 by a power of 1. Let the rope AC be fastened to a solid beam at A, and passing under the groove of a movable pulley D, be brought over a fixed pulley E; the only use of which is to render the application of force more convenient (127). Let a weight R be suspended from the central axis of the movable pulley D, and a force of power P, applied at the end of C; under these circumstances R will obviously be supported equally by the power P and the beam A, which, reacting against the power applied, aids in keeping the weight elevated in the same ratio as P does, action and reaction being equal and contrary (61), and accordingly R will be supported by a force P, equal to one-half its own weight. Hence in the single movable pulley, equilibrium is obtained when the power is to the resistance as 1 to 2. In the pulley, as in the lever, time is lost as power is gained, for a little reflection will show, that for R to be raised one inch, P must fall through two inches, as the end of A is immovable.

Fig. 77.



129. Sometimes a pulley is compound, consisting of two portions termed blocks, AB, each containing two or more single pulleys. In such an arrangement, each fold of string sustains a share of the weight, or resistance; and equilibrium will result when

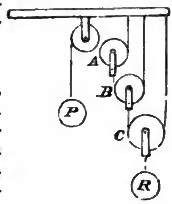
P : R : : 1 : number of strings on the lower block.

And in the pulley figured in the margin, the folds of string in the lower block being 4, a power of 1 will sustain a resistance of 4.

130. Instead of the string folded on the pulley being entire, it is sometimes divided into several portions, each pulley hanging by a separate string, one end of which is attached to a fixed beam. Here a great increase of power is gained, attended by a corresponding loss of time, as the power P must move much faster than R, and acquire considerable momentum, which, indeed, becomes

active in enabling it to put R in motion. In such a system, the gain of power may be determined by calculating that power of 2, whose index is the number of movable pulleys.

Fig. 78.



$$P : R :: 1 : 2^n.$$

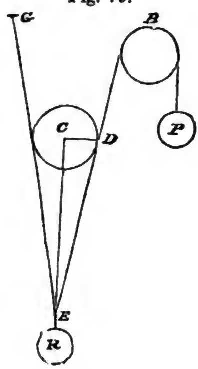
In the system of pulleys, figured in the margin, there are three movable pulleys; now the third power of 2 is 8, and accordingly, with such an arrangement, we can, with a power of 1, counterbalance a resistance of 8. The fixed pulley in this system does not increase power, but merely affords a more convenient mode of applying force (127). When the pulleys are connected each to a separate string, the ends of the latter being attached, not to a beam, as in the last case, but to the resistance to be overcome, some mechanical loss is sustained, and equilibrium is obtained, when

$$P : R :: 1 : (2^n—1)$$

2^n being the power of two, whose index is the number of movable pulleys.

131. In the preceding cases, the strings of the pulley or their folds are supposed to be parallel; when this is not the case, some alteration takes place in the condition of equilibrium. Taking the case of a single movable pulley, equilibrium occurs, when the power is to the resistance, as radius to twice the cosine of the angle, in which the weight acts. Let CR be the direction in which the weight or resistance R acts; produce BD until it meets CR at E. Then, if DE be taken to represent the amount of power at P; it may, by the resolution of forces (66), be supposed to be the resultant of two forces, one acting in the direction CE, and effective in raising the weight R; the other, CD, being counteracted by an equal and opposite force arising from the tension of the string EG; and as the two folds of the string GE, BE are equally active in sustaining R, 2 CE will represent the whole weight sustained by the power P and

Fig. 79.



$$P : R :: DE : 2\ CE :: \text{rad} : 2 \cos DEC.$$

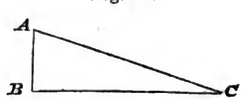
When the strings become parallel, the angle DEC vanishes, and its cosine becomes radius, then P : R :: 1 : 2, as already explained (127).

The pulley has been referred, with great justice, to the lever, of which indeed it may be considered as a modification; the radii of the pulley representing the arms of a lever, on which, by means of the string, the power is made to act.

3. INCLINED PLANE.

132. The action of this mechanical power depends upon the simple principle, that a body free to move can be supported only by a force equal to its own weight, unless it can deposit a portion of this weight on a fixed obstacle, in which case it can be supported by a smaller force.

Fig. 80.

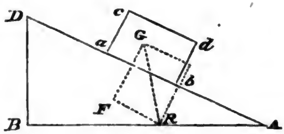


An inclined plane consists of any substance sufficiently hard, inclined at a given angle. In every plane three parts are distinguished, its height AB, its length AC, and base BC. In our theoretical considerations of its action, its sur-

face must be considered as absolutely hard and smooth, conditions to which the best constructed instruments afford, of course, but distant approximations.

133. Suppose a solid body, *abcd*, to be placed upon an inclined plane, ABD, so that it may slide down under the influence of gravitation. To calculate the force required to retain it on the plane, draw a perpendicular line, GR, from the centre of gravity (46) G, to represent the direction of the earth's attraction for it. By means of the parallelogram of forces (66), decompose this resultant into two forces GF, perpendicular to the plane DA, and G*b* parallel to it. It is seen at once that the force GF is entirely opposed by the surface of the plane, and G*b* will represent the actual intensity of force acting on the body *abcd*, and which is active in drawing it down the plane. Consequently, the force necessary to retain the body on the plane, will bear the same ratio to the total weight of the body, as the line G*b* does to the diagonal GR, or, what comes to the same thing, as the height of the inclined plane is to its length, because the triangle G*b*R = triangle DBA; and using the letters referring to the last figure, equilibrium will be obtained on the inclined plane, when P : R : : DB : DA: therefore the less the height of the plane, the greater the weight that can be sustained on it by a given power. Here, as in the other mechanical powers, velocity is lost as power is gained, for the vertical height to which the body is raised by means of the inclined plane, is equal only to the height of the plane, or sine of the angle of inclination. And, as in the preceding figure, DA is considerably longer than DB, it will, supposing the weight raised to pass over equal spaces in equal times, necessarily require a longer time to move it through the space DA than DB.

Fig. 81.



134. If an inclined plane be supposed to be wound spirally around a cylinder, in a manner similar to that in which spiral paths are carried round

Fig. 82.

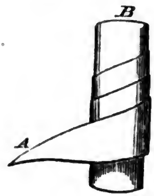
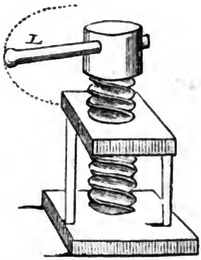


Fig. 83.



mountains to lessen the steepness of ascent, we have a *screw*, one of the most useful modifications of a simple machine. The edge of the flexible inclined plane A, wound round the cylinder B, constitutes the *thread* of the screw, and projects to a certain distance beyond the cylinder on which it is supposed to be wound. To use the screw, a hollow spiral is carved in the inside of a block of wood or metal, termed the female screw; this hollow spiral must be of such a size as to admit the projecting thread of the first, or male screw. Thus constructed, the male screw is generally turned by means of a lever,

fixed into its head, thus, indeed, forming a compound machine, the power of the lever being added to that of the simple screw. The power of the screw increases with the circumference of the circle described by the lever L to which the power is applied, and with the diminution of the distance between two contiguous threads of the screw, measured in a direction parallel to the axis. Calling this distance D, and the circumference of the circle described by the lever, L, equilibrium will be obtained, when

$$P : R :: D : L.$$

135. When two inclined planes are placed with their bases approximated, as AB, we have a wedge; which is a triangular prism, contained by plane figures, of which two that are opposite are equal, similar, and parallel, the others being parallelograms.* This is occasionally used as a mechanical power to lift heavy weights to small elevations, but is more generally used for the purpose of cleaving timber; the edge being introduced into a cleft made to receive it and the wedge forced in by repeated blows of a hammer upon its back. The great advantage of the wedge appears really to depend upon the percussion used to urge it into the mass of timber, &c., exciting vibrations between the particles of the solid, and thus permitting the edge to introduce itself between them. Certainly the direct action of a weight pressing upon the back of the wedge, can bear no comparison with the immensely greater effect gained by percussion.

Fig. 84.

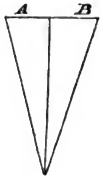
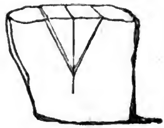


Fig. 85.



136. Theoretically speaking, it has been supposed that the power gained by the wedge, bears the same proportion to the resistance to be overcome, as half its back does to its height. Thus, a weight of 60 may be raised by a force of 20, providing we use a wedge, the half of whose back shall bear such a proportion to its length as 20 does to 60, or 1 to 3. The only part of this theory which is really supported by practical observation is the fact, that the power of the wedge increases, as its width or back diminishes. Many of our domestic instruments are modifications of wedges; a saw is composed of a series of them, and knives, scissors, razors, are nothing more than fine saws. Needles, pins, &c., may be considered as acute wedges.

137. In this outline of the properties of the mechanical powers, or simple machines, some important sources of resistance to their action has been omitted; because the consideration of them, as applied to their theory, is rather a branch of practical mechanics, than of the elementary portions of physical science. Friction (95), the rigidity of cordage, and the inertia (18) of the several parts of the machine itself, are important objects of study to the mechanic, as they oppose very important obstacles to the development of the full mechanical power of a machine, and prevent his obtaining such an amount of power as theoretical reasoning would lead him to anticipate.

138. In that elaborate and wonderful part of the animal economy, the muscular system, we have much to admire and wonder at, in the adaptation of power, to move the bony levers constituting the skeleton. Here, where great power, rapidity of movement, and elegance of figure, are equally attended to, we find evidence of infinite wisdom in the adaptation of mechanical power, apparently the least advantageous, to the most important motor functions of the body. In considering the mode in which *extension* of the limbs, especially

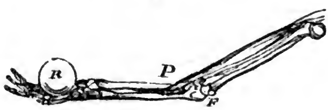
* Euclid, B. xi. Def. 13.

of the upper extremities, is performed, we see a set of levers of the first kind (122); or those in which the power and resistance are at opposite ends, and the fulcrum intermediate, called into action. In the *flexion* of the limbs, we have a set of beautiful examples of levers of the third, or that kind, in which the resistance and fulcrum are terminal, and the power intermediate (123). And in certain other muscular efforts, as raising the body on tiptoe, and depressing the lower jaw, we have examples of levers of the second denomination, in which the resistance is intermediate between the fulcrum and power.

Although the insertion of the flexor muscles, causing the limbs to act as levers of the most disadvantageous kind, might appear, at a superficial glance, to render the action of the limbs less energetic; a moment's reflection will show that by the insertion of muscle near the fulcrum, we gain an immense increase of velocity at the other extremity of the lever (123), generating a degree of momentum infinitely more fitted for the purposes required by the movements of the limbs than if by their insertion further from the fulcrum, they had been so placed as to exert their power to the greatest mechanical advantage. For this, at first sight, apparent advantage would have permitted us to use our now agile limbs with extreme slowness, with the additional disadvantage of unsightliness.

In the act of flexing the arm, for example, the fulcrum F is formed by the condyles of the humerus at the elbow joint, the resistance is the weight, R, in

Fig. 86.



the hand, and the power is applied at P by the contraction of the muscle attached to the radius. When this muscle (biceps flexor cubiti) contracts, the hand R describes a much longer curve in a given time (120, 123) than P, therefore a great amount of velocity, and consequently a considerable momentum (71) become generated.

139. The following are some among many examples of levers in the human body.

A. *Fulcrum between the Power and Resistance.*

POWER.	FULCRUM.	RESISTANCE.
Triceps extensor cubitii and anconæus.	Condyles of humerus.	Arm and hand, with any weight attached to them.
Muscles arising from tuberosities of ischia, and inserted into the lower extremities.	Heads of femora.	Weight of the trunk, when flexed upon the thighs.

B. *Fulcrum terminal, Resistance intermediate.*

Muscles connected with tendo achillis.	The floor pressed by the toes.	Weight of the trunk pressing on ankle-joint.
Digastricus, and other depressors of the lower jaws.	Articulation of the lower jaw.	Action of the temporal and masseter muscles.

C. *Fulcrum terminal, Power intermediate.*

Biceps flexor cubiti and brachialis.	Condyles of humerus.	Weight of arm and hand.
Deltoid.	Glenoid cavity of scapula.	Weight of the arm.

140. Of compound pulleys we should scarcely expect where all is characterized by beautiful simplicity, to find any examples; of simple pulleys, merely to alter the direction of motion (127), we have a few instances. The structure of the pulley-like organ is always extremely simple, usually being merely a groove in the bone covered with cartilage, sometimes a bony hook, and in another case a tendinous ring. The tendon of the obturator internus, which in passing out of the pelvis, glides in a groove in the ischium, so as to alter its direction, affords an example of the first and simplest pulley in the human body: the hook-like process through which the tendon of the circumflexus palati glides, so as to alter its direction to a right angle, illustrates the second form of pulley; and of the third, we have an example in the tendinous ring in the depression of the frontal bone, through which the tendon of the obliquus superior muscle of the eye glides, becoming thereby bent to an acute angle.

141. We have no instance of the occurrence of the inclined plane or its modifications in the skeleton; the sacrum is certainly not an example of the wedge, notwithstanding its figure. The only approach to a wedge in animal structure which I am acquainted with, is the bony apparatus discovered by Sir Philip Egerton, in the neck of the ichthyosaurus, an extinct antediluvian reptile. Three wedge-like bones have been described by him as connected with the cervical vertebræ, and fitting into spaces between them; these wedges are supposed to have been withdrawn when the animal flexed the head upon the trunk, and to be introduced between bodies of the vertebræ when the head was raised: so as to diminish that vast muscular effort which would otherwise be required, to keep the enormous and disproportionate heads of these animals extended.

NOTE.

On the subjects treated of, in the preceding five chapters, the student may consult, with advantage, the excellent Elements of Physics of M. Peschel, translated by Mr. West, the Illustrations of Mechanics, by Professor Mosely, Sir David Brewster's edition of Ferguson's Mechanics, and Dr. Olinthus Gregory's Mechanics, as well as the monographs in Sir David Brewster's Encyclopædia, Dr. Lardner's Cabinet Cyclopædia, the Cyclopædia Metropolitana, and the Treatises published in the Library of Useful Knowledge. Among continental authors, the works of Poisson, Pouillet, Biot, Hauy, Quetelet, &c., should be carefully studied. See also, Muller's "Physics," chapters I. and II., American edition, Lea & Blanchard, 1848.

In the Essays on Mechanics, by the late Dr. Wood, of Cambridge, and Professor Whewell, the reader will find the law of statics and dynamics mathematically treated. The propositions in the Principia of Newton will of course be studied with attention by all who desire an intimate acquaintance with them, whilst those who content themselves with a more popular and general knowledge of these subjects, would do well to consult Euler's Letters to the

Princess of Anhalt-Dessau. To facilitate the study of these works, the following references to the portions bearing on the contents of the preceding chapters may be useful to the student:

Chap. 1.—Newton, bk. i. def. 1. 3; bk. iii. rule 3; Euler, vol. 1, letters 1, 69, 74, and vol. 2, let. 7, 12.
Chap. 2.—Newton, bk. i. def. 5, 6, 7; bk. iii. prop. 1, 7, 9; Euler, vol. 1, let. 45, 58, 62, 68.
Chap. 3.—Newton, bk. i. cor. 1, 2, def. 8; bk. iii. prop. 19; Euler, vol. 1, let. 3, 71.
Chap. 4.—Newton, bk. i. cor. 6, prop. 50—55, sect. 7; bk. ii. prop. 40, sect. 1—3, 6; bk. 3, prop. 19, 20, 24; Euler, vol. 1, let. 45—68.
Chap. 5.—Newton, bk. i. cor. 6, scholium.

CHAPTER VI.

GENERAL PROPERTIES OF NON-ELASTIC FLUIDS AT REST. (HYDROSTATICS.)

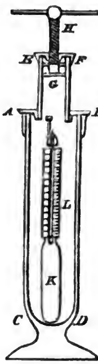
Properties of Fluids, 142. *Elasticity of*, 143. *Compressibility of Water*, 144. *Equality of Pressure*, 145. *Level Surface of*, 147. *Level of the Sea*, 148. *Hydrostatic Pressure*, 149. *Upward Pressure*, 152. *Lateral Pressure*, 156. *Centre of Pressure*, 157. *Communicating Vessels*, 158. *Equilibrium of Solids in Fluids*, 160. *Principle of Archimedes*, 161. *Specific gravity of Solids*, 162—165—*of Liquids*, 166—*of Gases*, 169. *Areometer*, 167. *Table of Specific Gravities*, 171. *Waves or Undulations*, 172—174—*Reflection of*, 175—*Interference of*, 176.

142. **Fluids**, or liquids, are characterized by the extreme mobility of their molecules on each other, by which they are prevented having any distinct form like solids, always assuming that of the vessels containing them. Fluids obey all the laws which have been explained in the preceding chapters, with such modifications as depend upon their molecular constitution. They obey most strictly the attraction of gravitation (38), and are capable of assuming motion, in the same manner as solids, in cases where the ready mobility of their particles on each other does not interfere. A mass of water, or other fluid, in falling from a given height, would produce effects as important as an equal mass of any solid, if no opposing causes existed; and the reason why no one would fear the falling of a pailful of water on his head from an elevation, capable of giving to the pail itself a degree of momentum sufficient to fracture his skull; is, that in falling, the water is opposed by the air, and, from the ready manner in which its particles allow of separation, it becomes divided into a kind of irregular shower, producing no effects likely to be dreaded from their mechanical violence. If the particles of water were tied together by increased attraction of aggregation, as by freezing, then its mechanical effects would be as serious as those of a mass of stone.

143. Fluids have been divided into elastic and non-elastic: a distinction by no means well defined, for it is quite impossible to draw a distinct line of demarkation between those fluids which, as water and alcohol, are but slightly compressible, and therefore but slightly elastic; and those which, like air and all gases, admit of ready compressibility, and consequently are endowed with a considerable share of elasticity. The properties of the one class are common to the other, with but slight modifications. We shall, therefore, first examine the physical characters of fluids *generally*, reserving for the ensuing chapter a consideration of the properties peculiar to the eminently elastic fluids, or gases.

144. Liquids, properly so called, of which water may be taken as the type, are but slightly compressible; this character indeed was for some time doubted, as the celebrated experiment, performed by the Florentine academicians, of enclosing water in an hermetically-sealed ball of gold, and causing the fluid to percolate the pores of the metal by pressure, was for a long time considered conclusive on this point, although all that it really proved was the porosity of the metal. From the experiments of Canton, the compressibility of water under the pressure of our atmosphere, equal to fifteen pounds on each square inch, was estimated at 0.000044; whilst Mr. Perkins has lately estimated the compression under the same pressure at 0.000048; and Professor Oersted, by means of an extremely accurate set of experiments, has fixed on rather more than 46 millionths as the degree of compression experienced by a given bulk of water, for each additional pressure of our atmosphere. The apparatus used by Professor Oersted consisted of a very strong glass vessel ABCD, having firmly cemented into its upper part a short iron cylinder EF, in which a piston G, capable of being moved by the screw H, moves air-tight. A bottle K, into the neck of which is firmly fixed a capillary tube L, furnished with a scale graduated into fractions of an inch, is placed in the glass vessel, ABCD. By a previous experiment, the contents of the tube L as compared with the bottle K are ascertained. In some of the tubes used, one inch in length held 80 millionths of the contents of the bottle. The whole apparatus, bottle and tube, being filled with water, or other fluid whose compressibility is to be determined, the screw H is turned, the piston G descends, and the pressure being communicated through the fluid in ABCD, the contents of the bottle K are compressed, the amount of compression being measured by the descent of the fluid in L. The compression of the fluid is shown by the descent of a bubble of air in the tube, entangled in the upper part of L, before placing it in the larger vessel ABCD. By means of this apparatus, Professor Oersted determined the compressibility of the following fluids to be for each additional pressure of an atmosphere (190) in millionth parts of the whole bulk—

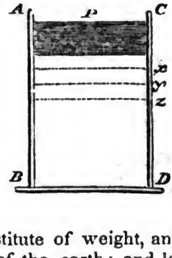
Fig. 87.



Mercury	2.65
Alcohol	21.65
Water	46.65
Ether	61.65

The compressibility of liquids is also proved by the faint elasticity they really possess, shown by the copious scattering of drops in all directions, when water, or any other liquid, is poured from a height on a smooth surface. A vessel filled with a liquid gravitates, in common with its contents, towards the earth; the fluid gravitating also independently of it, as, on piercing a hole in the containing vessel, it escapes towards the earth.

Fig. 88.



145. Liquids, on account of their extreme mobility, are capable of communicating pressure exercised on them equally in every direction, a property constituting the most interesting characteristic of this class of bodies. Let ABCD be a vessel containing a liquid destitute of weight, and therefore theoretically unacted upon by the attraction of the earth; and let the shaded portion P be a solid piston, also destitute of gravity, moving air-

tight in AC, and exactly covering the surface of the liquid. Now, as P is without weight, it does not press upon the fluid, and the sides of the vessel may be pierced without its escaping. But if we place on P a weight of 100 pounds, it will attempt to descend, and would reach the bottom of the vessel were it not opposed by the water. Accordingly, the upper layer of fluid x becomes pressed by the piston, and would fall, if not supported by the subjacent stratum y, which thus in turn becomes pressed; this acts on the layer z, and this on the subjacent layers, transmitting the pressure exerted by the weight with which the piston is loaded to the bottom of the vessel. And as the whole base BD supports the pressure of 100 pounds, it follows that one half the base supports but 50, and ·01 the base but one pound, &c. From these considerations we may safely infer that,

A. Pressure is transmitted by fluids from above to below, upon horizontal surfaces, without becoming diminished.

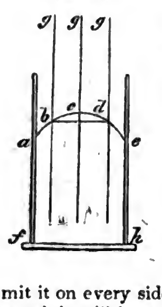
B. It is equal in every portion of the fluid.

C. It is proportioned to the area of the surface pressed.

146. The same phenomena will be observed at the sides of the vessel ABCD, for if any portion of it be perforated, the liquid rushes out, providing the weight of 100 pounds still continues to act upon the piston; and if a portion of one of the sides of the vessel be cut out, equal to the area of the piston, the force required to be applied to keep the fluid in the vessels would be found to equal that pressing on the piston P, or 100 pounds. Finally, if a perforation be made in P itself, the pressure still continuing, the liquid rushes from below, and escapes in a jet d'eau, proving satisfactorily that *liquids transmit forces acting upon them, equally in all directions.*

147. Liquids can never attain a perfect state of rest, and be in complete equilibrium, unless the particles in the upper and exposed layer form a surface perpendicular to the forces acting upon it; and every molecule of the mass of fluid experiences equal and contrary pressures. To render the first condition intelligible, let *aefh* be a vessel full of water, or other fluid; to attain a perfect equilibrium, the surface of the fluid must be level and in a plane perpendicular to the forces *ggg*, representing the directions of the earth's attraction. If, instead of forming a level surface, the fluid be supposed to describe a curve, *abcde*, a small horizontal layer, as the line *bd*, will be pressed by the weight of the molecules above it; this pressure will become transmitted laterally (154), and the molecules of fluid at *b* will be acted upon by this lateral pressure, and pushed outwards, because there is nothing to oppose this action; immediately other particles take their place, and being acted upon in a similar manner, become pushed out in their turn; and this effect continues until all that portion of fluid standing above the horizontal line *bd*, becomes drawn down to form one level surface, and then the curve *bcd* vanishes, and an horizontal surface, extending from *a* to *e*, perpendicular to the forces *ggg*, is produced. The fluid will then be in equilibrio, providing the second condition obtains, that every molecule in the interior of the mass of fluid experiences equal and contrary pressures. That this is the case is evident, for every particle of fluid receiving the pressure of those above it tends, in consequence of the equality of pressure (145), to transmit it on every side; and if the pressure on two sides of the particles be unequal, it will be acted upon by the strongest force, and continue to move until it has attained a situation where all the forces acting upon it become equal. The only exception to the law of the level surface of liquids arises from the capillary attraction, or repulsion, exerted by the sides of the vessel (25).

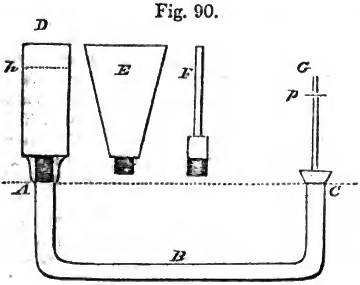
Fig. 89.



148. We have a beautiful example of the truth of the law of equilibrium of fluids (147) in the figure of the surface of oceans and seas in a calm state, by which the cause of their superficial curvature becomes immediately apparent. We know that, in common with everything belonging to our globe, the seas obey the force of gravitation; and as this is exerted from the centre of the earth (38), the oceans and seas necessarily assume the spherical form, because this is the only figure whose surface is perpendicular to all the radii emanating from its centre. On this account, where a standard place of observation is required for very accurate barometric or other experiments, so as to enable observers in different parts of the world to compare the results of their observations, the level of the sea, or a given distance above it, is always chosen. The only considerable exception to the perfectly circular outline of the seas and oceans, arises from the centrifugal force generated by the rapid rotation of the earth (59). Among minor causes affecting the regular curve surface of the great mass of water on our globe, may be mentioned those which arise from certain physical features of the earth itself; the mountainous elevations on its surface attracting, by lateral gravitation (41), the water of seas and oceans towards them. If the mountains of the Cordilleras were about 100 times higher than they are, the seas would, by their attraction, be elevated into liquid mountains on both sides of the coasts of America, and the ports of France and Japan be left dry. The peculiar directions of winds and currents are sources of disturbance to an important extent, causing elevations in particular and isolated masses of water; thus the level of the Red Sea at high water is more than thirty-two feet higher than the Mediterranean. The level of the Pacific at Callao is more elevated than the ocean at Carthagena by twenty-three feet; whilst the ocean at Dunkirk and the Mediterranean at Barcelona are at the same elevation.*

149. The pressure of a fluid on the bottom of the containing vessel is altogether independant of its shape, *and is equal to the weight of a column of fluid, whose base is the same as that of the containing vessel, and whose height is equal to that of the contained fluid.*

Fig. 90.



The best mode of proving this statement is by means of the apparatus contrived by M. Haldat, consisting of a bent glass tube ABC, having at A a collar cemented, into which vessels of different shapes, DEF, can be screwed. The tube ABC is filled with mercury up to the level of the dotted line AC, and the tube GP fixed into C. The cylindrical vessel D is then screwed into A, and water poured in as far as h; the base of the column of water will of course be equal in area to that of the surface of the mercury in the tube A. The

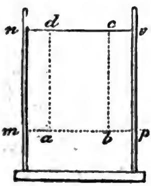
* Pouillet, Physique, p. 115.

mercury will then rise to a certain height in G, as p; in consequence of the pressure of the water in D on the surface of the mercury in A. Then unscrew D and fix on A the conical vessel E, and pour in water until it has attained the same vertical height as in D; on examining the mercury in G, it will be found at the same point p as when the cylinder D was fixed on A. Remove E and replace it by F, and on pouring in water to the same height, the mercury in G will attain the same elevation as before. Proving satisfactorily that the pressure exerted by masses of fluid is quite independent of their quantity; for the pressure was the same when either of the differently sized vessels D, E, F, were used, each containing very different quantities of water; in each, however, the actual base formed by the surface of the mercury, and the height of the column of water were the same, and the pressure, as above stated, varies solely with the vertical height, and area of the base, of the column of fluid. In the case of the funnel-shaped vessel E, the inclined sides support part of the weight of the fluid.

150. We may readily calculate the amount of fluid pressure on the bases of containing vessels, by setting B for the base of the column, H for its height, and D for the density of the fluid. The pressure upon the base B will be equal to $B \times H \times D$, for $B \times H$ will be equal to the volume of the fluid; and to have the weight, this product must be multiplied by the density D.

151. From this law (149), we are enabled, with a given bulk of fluid to produce a very small, or a very considerable amount of pressure on the base of a vessel. For, with a quantity of fluid $= F$, a certain amount of pressure can be exerted on a given area, when the vertical height of the fluid is $= h$; ten times that pressure can be produced by narrowing the capacity of the vessel so that the vertical height of the fluid may be $= 10\,h$, and conversely the pressure may be lessened to $\frac{1}{10}$ by so inclining the sides of the vessel that the vertical height of the fluid may be only $= \frac{h}{10}$. By availing ourselves of this law, a cask may be readily burst by means of hydrostatic pressure. For this purpose let a cask be filled with water, and a tube about twenty feet in length be cemented into the bung-hole. On pouring water into the vessel, pressure is exerted, equal to the area of the vessel multiplied by the height of the column of water in the pipe, and a degree of force sufficient to burst the cask with violence is generated. The well-known philosophic toy, called the hydrostatic bellows, illustrates the same fact: this consists of two boards connected loosely by strong leather; into the upper board is fixed a long glass tube, and on pouring water into the latter the boards become separated, even when previously pressed together by a considerable weight. In this manner, when the space between the boards is nearly filled with water, and a man stands on the upper board, an ounce of water poured into the pipe will exert sufficient force to elevate him considerably, notwithstanding the weight the fluid pressure has to overcome.

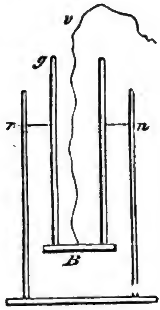
Fig. 91.



152. In accordance with the general law of fluids exerting pressure equally in all directions, it follows that every layer of fluid presses as powerfully upon every superposed stratum, as it does upon all subjacent ones. Thus it is evident that all the particles composing any particular stratum of fluid, as *mp*, must be pressed upon by all above them, in the same manner as if they supported a solid piston equal to the fluid mass *nvmp*. If then we regard a portion only of the layer *mp* as *ab*, we can readily understand that this is at once pressed from above downwards by the column *dcab*, and from below upwards by an exactly equal force, in such a manner that, if a solid cylinder were immersed in

the fluid with its base resting on *ab*, the upward pressure would tend to throw it out of the fluid. These theoretical considerations may be readily verified by means of an apparatus consisting of a stout glass tube, *g*, having a plate of brass, B, pressed against its base, and retained *in situ* by the string *v*. On immersing the whole in a vessel filled with water to *nn*, the plate will be pressed against the mouth of the tube by the upward pressure of the fluid. If water be then poured into *g* until it nearly reaches the external level *nn*, the plate will obey the attraction of gravitation, and fall to the bottom of the vessel, as the upward pressure of the water below the plate B, becomes neutralized by the downward pressure of the water in the tube *g*.

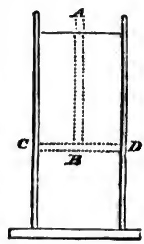
Fig. 92.



153. On account of this upward pressure of fluids, if a hole be made in the bottom of a ship the water rushes in; to effectually oppose which, a force must be applied, equal to the weight of a column of water, whose base is of the same area as that of the aperture in the vessel, and whose length is equal to the depth of the hole from the surface of the water. Hence, in vessels of large draught, the keels should possess considerable strength to enable them to oppose the upward pressure, exerted by the water in which they float.

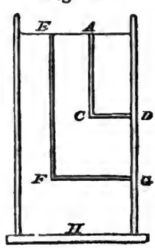
154. As a consequence of the law of equal pressure, every portion of the sides of a containing vessel is exposed to pressure, corresponding to the weight of the fluid pressing against it. In the vessel of water, ACD, if a particle of fluid situated at B be pressed by the column of water AB, it will for reasons already stated, be at the same time pressed upwards (152) by an equal force, and this pressure will be communicated laterally to the particles lying on the same horizontal layer between BC and BD. Thus every point in the sides of the vessel is pressed with a force of the same intensity, as that with which the fluid particles contained in the horizontal layer corresponding to it, are. As a general rule, the pressure supported by the sides of a containing vessel is equal to the weight of a fluid column, having for its vertical height the depth of the centre of gravity of the side below the surface; and for its base, a surface equal to that of the side of the vessel.

Fig. 93.



155. The lateral pressure increases with the depth of the fluid; for in the vessel EADGH the fluid column AC transmits its pressure (154) to the horizontal layer CD to D: and the column EF pressing upon the layer FG, has its force transmitted by FG to G; then the pressure at G must be greater than at D, because EF is longer than AC. Therefore the formula already given for calculating the pressure on the base (150) will apply to the lateral pressure; letting B represent the side instead of the base of the vessel.

Fig. 94.



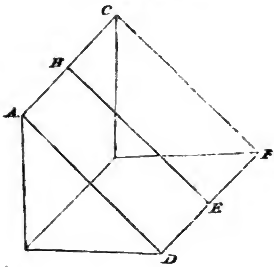
In a vessel of water of 5 feet deep, the pressure on a square inch of lateral surface at

1 foot deep, will be = ½ pound
2 . . . . . = 1 . .
3 . . . . . = 1½ . .

4 feet deep will be = 2 pounds
5 . . . . . = $2\frac{1}{2}$ . .

156. When the pressure upon the base of a cubical vessel of water is known, the lateral pressure can be readily calculated, for the pressure upon any one side of a cubical vessel, filled with fluid, is one-half of the pressure on the base. For the bottom sustains a pressure equal to the whole weight of the

Fig. 95.

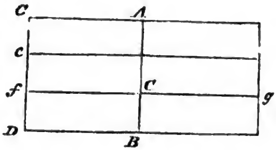


fluid, and the pressure sustained by the side is equal to the weight of the prism ABCDEF, which is half the cube,* and therefore equal to half the pressure on the base.

From this fact follows the remarkable circumstance that the fluid, in a cubical vessel, produces a total amount of pressure three times as great as its own weight; for if the latter be = 1, and as upon each of the four sides it produces a pressure equal to half that on the base, $\frac{1}{2} \times 4 = 2$; and upon the bottom a pressure equal to its own weight, the total pressure exerted by it must be $2 + 1 = 3$.

157. The point where all these pressures (149—156), in a mass of fluid, are equally balanced, is termed the *centre of pressure;* this would be identical with the centre of gravity (46), if the lower layers of fluid were not compressed by the weight of those above them, on which account it is always somewhat lower than this point. In a vessel whose sides are parallelograms, the centre of pressure is found by bisecting the horizontal sides, by the line AB, and dividing GD into three equal portions by the lines *ef;* produce *f* to g, and the point where this line intersects AB will correspond to the centre of pressure C. In a triangular vessel supported on its base and filled with fluid, the centre of pressure is at one-fourth of the vertical line AB, reckoning from the base, viz. at C. In a similar vessel resting on its apex, the centre of pressure is at C, in the middle of the vertical line AB.

Fig. 96.



* Euclid, Book II., props. 28 and 40.

Fig. 97.

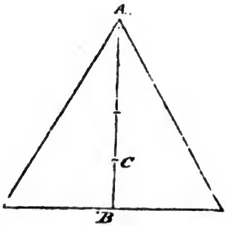
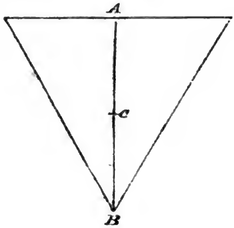
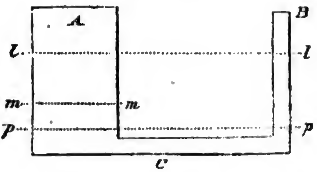


Fig. 98.



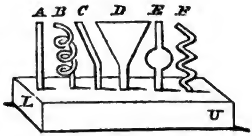
158. When several vessels, of the same or different sizes, communicate together, the same conditions of equilibrium obtain, as when fluids are contained in a single vessel (147). Let A B be two differently sized vessels connected by the tube C, on pouring water into them up to the line *ll*, it will be found to present a level surface in both: and the fluid in each will be at the

Fig. 99.



same elevation; for if the water in A, instead of being at *l*, were at *mm*, it is obvious that the layer of fluid *pp* would be submitted to unequal pressure, being in B pressed by the long column *lp*, and in A pressed only by the shorter column *mp*, and consequently equilibrium could not exist (147). Therefore the particles of fluid acted upon by the strongest force will move, and attain a state of rest only when the level of the fluid is the same in both vessels. This law obtains when the connected vessels present the greatest variety in shape or size. If the tubes ABCDEF be fixed into a common reservoir, LU, and water be poured into D, it will attain exactly the same elevation in each of the tubes, notwithstanding the difference in the figure and size. The only circumstance introducing the slightest exception to this law is capillarity (22), by which, if one of the tubes or vessels in the above figures be very narrow, the water, or other fluid, will have a tendency to rise to a higher elevation than the fluids in the wider ones.

Fig. 100.



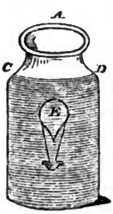
159. The above law applies only when the communicating vessels are filled with the *same* fluid; for if fluids of different densities incapable of mixing, as water and mercury, be used, the elevations acquired by each will be found to be in the inverse ratio of their specific gravities (10, 162). Let mercury

101.

be poured into the tube AB until the horizontal surface C becomes filled, then pour water into B, and it will be found that, to rise the mercury in A to the height of one inch, a column of water, rather more than 13·5 inches high, will be required in B; in consequence of the specific gravity of mercury, as compared to water, being as 13·59 to 1.

160. When a solid is immersed in a fluid, it displaces a quantity of the latter equal to its own bulk, a legitimate consequence of the impenetrability of matter (2). If this quantity of fluid be lighter than the solid, the latter will sink, but if heavier, it will swim: this has been already alluded to (43). But if the fluid displaced be the same weight as the immersed solid, the latter will remain at rest in the fluid, in whatever position it be placed; a circumstance arising from the force of gravitation acting equally upon the solid and the fluid displaced, the quantities of matter in each being equal. Fishes appear to be in this state of equilibrium when immersed in their own element; and for the purpose of enabling them to preserve this state at different depths they are provided with an air-bladder, by compressing or expanding which, they are enabled to cause their bodies to acquire the same density as that of the water in which they live. At a very great depth, the air in this air-bladder becomes considerably condensed, and on suddenly rising to the surface it expands; and it occasionally happens that this takes place with such force, that the muscular efforts of the animal are unable to control it, and the organ is ruptured, causing an extravasation of air into the surrounding tissues. The hydrostatic toy known as the Cartesian devils, in which a hollow glass figure, partly filled with water, floats or sinks in a vessel of water by pressing the piece of caoutchouc with which the latter is covered, is a popular illustration of these facts. Let AB be a glass vessel filled with water up to CD, having a little figure of thin glass, as a balloon E placed in it, previously allowing enough water to enter the balloon to render it nearly of the same density as the water in AB. A little opening exists at the lower part of E so as to allow water to enter or escape from it. Over the mouth A is tied a piece of sheet caoutchouc. If E floats to CD, and the cover A be pressed inwards into the jar, the air above CD will be compressed, the pressure will be conveyed through the water to the air contained in E; this will consequently be compressed into a smaller bulk, and enough water will enter E to render it heavier than the water, and it falls to B. On removing the hand and taking off the pressure, the air in E expands, expels the water which had previously entered it, and it again rises to CD.

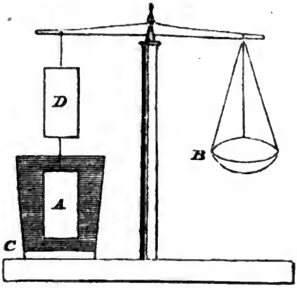
102.



161. The well-known hydrostatic principle that solids, immersed in fluids, displace a quantity of the latter equal to their own bulk, was first observed by Archimedes, who studied it with no less industry than success. This sage moreover discovered *that a body, when immersed in a fluid, loses a portion of its weight equal to that of the displaced fluid.* The most satisfactory mode of proving the correctness of this important law is, by suspending from one of the arms of a balance a hollow cylinder, D, having a cylindrical mass of any substance, A, capable of exactly fitting into it, hanging from it by means of a thread. Place weights in the scale-pan B until the solid cylinder A and the hollow one D are exactly counterbalanced; then pour water into the vessel C until A is completely immersed, and immediately the pan B will preponderate, the solid cylinder appearing to have lost a considerable portion of its weight; then

pour water into the vessel D until it is quite full, and as soon as this is done, the balance will once more be in equilibrio. Now, as the cylinder D is of

103.



such a size that the solid mass A will exactly fit into its interior, it follows that the water with which D is filled is precisely equal in bulk to the solid A; proving most satisfactorily that the apparent loss of weight suffered by A, on being immersed in water, is precisely equal to the weight of a mass of fluid equal in bulk to itself. The apparent loss of weight of the mass A, observed on immersing it in water, arises from the upward pressure (152) of the fluid supporting the immersed solid, and opposing, to a certain extent, the attraction of gravitation (38).

162. The principle of Archimedes (161) affords a ready mode of determining the *specific density or gravity* (10) of any substance; for when a body is immersed in water and weighed, it, as above stated, suffers an apparent loss of weight equal to that of its own bulk of water; then, by knowing this weight as well as the absolute weight of the body when weighed in air only, we have all the elements for calculating the density of any substance. For the density of any substance is equal to its bulk, multiplied by the quantity of matter, or number of atoms that it contains. Water is generally taken as a standard to which all the specific weights of bodies are referred, and its specific gravity is assumed as 100 or 1000; thus, if a body is said to be of specific gravity 11·50, all that is meant, is, that a quantity of water, weighing 1000 grains, is exactly equal in bulk to a mass of the substance weighing 1150 grains. A cubic inch of water, at the temperature of 40°, weighs 252·953* grains, and a cubic foot 437102·4946. To obtain the weight of a cubic inch or foot of any substance, it is only necessary to multiply its specific gravity by the weight of an equal bulk of water.

163. The best mode of ascertaining the specific gravity of a solid heavier than water, is to suspend it by a hair, or piece of fine platinum wire, from a hook fixed in the bottom of one of the pans of a balance, and by placing weights in the opposite scale ascertain its exact weight, then immersing the solid completely in water it will appear to lose weight (161), and ascertain its exact weight when thus immersed. Subtract the weight of the substance in water from its weight in air, and divide the latter by the difference, the product will be the specific gravity required. The rationale of this process is sufficiently

* At the temperature of 62° the cubic inch of water weighs 252·458 grs., the logarithm for which is 2·40219.

obvious; the exact weight of the body is first learnt by weighing it in air; by ascertaining its weight when immersed in water, and subtracting this from its weight in air, we learn the weight of a mass of water equal in bulk to the body under examination, and by dividing the actual weight of the body by that of an equal bulk of water we ascertain the relation they bear to each other.

Ex. A piece of copper weighed in air 2047 grains, and in water 2024 grains; then 2047—2924=23, and 2047÷23 = 89; water being 1·0, hence the copper was 8·9 times heavier than an equal bulk of water.

164. If the substance be lighter than water, tie it to a piece of any heavy solid, whose weight in air and water is known, sufficiently large to sink it in water. Weigh the compound both in air and water, and ascertain the loss of weight; then, knowing the weight lost by weighing the heavy body by itself in water, ascertain the difference of these losses, and with this number divide the weight of the light body, the result will be its specific gravity. The rationale of this process is very plain, for the last loss is = the weight of a quantity of water, equal in bulk to the heavy and light bodies together; and the first loss is = the weight of water, equal in bulk to the heavy body, and consequently their difference is equal to the weight of a mass of water of the same bulk as the light body.

Ex. A substance weighed in air 600 grains, tied to a piece of copper, it weighed in air 2647 grains, and in water 2020 grains, suffering a loss of weight of 627 grains. The copper itself losing 23 grains when weighed in water; then 600 ÷ 604 = ·993, the specific gravity of the substance.

165. If the solid be soluble in water, it must be weighed whilst immersed in some fluid incapable of dissolving it, as alcohol, oil of turpentine, &c., and its specific gravity as compared with the fluid ascertained. All that is required to determine its density with regard to water, is to multiply the specific gravity thus found by that of the fluid employed.

Ex. A substance soluble in water was weighed in oil; its specific gravity, as compared to oil, was found to be 3·7. The specific gravity of the oil was 0·9 and $3{\cdot}7 \times 0{\cdot}9 = 3{\cdot}33$, the specific gravity of the substance as compared to water.

166. The specific gravity of a fluid may be discovered in several ways; the readiest mode is to compare the weights of equal bulks of distilled water and of the fluid whose density we are seeking. For this purpose take a phial of convenient size and carefully counterpoise it. Ascertain first the weight of water required to fill it, and then the weight of the same phial full of the fluid under examination; and, on subtracting from the latter the weight of the bottle, the weight of the fluid will be ascertained. Divide the weight of the fluid by that of the water, and the quotient will be the specific gravity.

Ex. A counterpoised bottle held 500 grains of water, and 412 grains of alcohol, then 412 ÷ 500 = 0·824, the specific gravity required, for 500 : 1000 : : 412 : 824.

166. Another and very convenient mode of finding the specific gravity of a fluid is founded directly on the fact of solids displacing a bulk of fluids equal to their own (161). For this purpose take a glass ball whose loss when weighed in water is known, then weigh it while immersed in any other fluid, and, subtracting this from the weight in air, ascertain this fresh loss in weight. Then its loss when weighed in the fluid, divided by its loss when weighed in water, will be the specific gravity required.

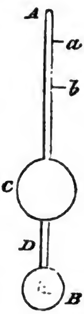
Ex. A glass ball lost 30 grains when weighed in water, and 24 when weighed in alcohol, and 24 ÷ 30 = 0·800, the specific gravity of the fluid, for 30 : 1000 : : 24 : 800.

167. The specific gravity of fluids is frequently very conveniently ascertained by means of the gravimeter, areometer, or hydrometer; an instrument

whose mode of action depends upon the fact of solids of a given weight sinking deeper in light, than in heavy fluids.

These instruments are made of various materials, as metal, ivory, and glass, according to the uses for which they are intended. Their action is always confined within a very limited range, unless they are of inconvenient length, and their indications are by no means mathematically correct, still, for very many practical important purposes they are extremely useful. As instruments of this class are frequently useful to the physician in his examination of certain animal secretions, it will be not altogether useless to describe the mode of graduating them. Procure a thin glass tube blown into the shape of the figure AB, and from three to 5 inches in length, place in the narrow part of the tube AC a thin slip of paper, and pour in mercury until, when immersed in distilled water, the whole iustrument will sink to within half an inch of its top. Then thrust, by means of a wire, a fragment of cork and a few pieces of sealing-wax into the smaller tude D; by holding it near the flame of a candle, melt the wax, and then allow the whole to cool. In this manner the mercury will be kept in the ball B, without any danger of its falling out on inverting the instrument. Replace the tube in distilled water, and very carefully mark with a file, the point where the stem A is intersected by the surface of the fluid; let this be *a*, then immerse it in a solution of salt, whose specific gravity is known; suppose this to be 1.030, and mark with a file the point where the stem is intersected by the surface of the solution; let this be *b*. With a pair of compasses take the distance *ab*, on a slip of paper of the same size as that previously placed in A, and divide this into thirty equal parts, and from the same scale divide the whole length of the paper until it has sixty equal parts marked upon it; and number these in fives; distinguishing every tenth division with a darker or longer line than the others. Then introduce this paper into the stem A, in place of the first piece, and push it down until the mark *a* corresponds to zero, or 0 on the paper scale; when this is done the latter may be retained in its place by a little varnish or gum; and the top being closed by the blow-pipe, the instrument is completed. To ascertain the specific gravity of any fluid by it, immerse it in the fluid, and note the graduation to which the level of the fluid corresponds, add 1000 to this, and the product is the specific gravity of the fluid very nearly; thus, if the stem sinks to 15, the specific gravity of the fluid is 1015

Fig. 104.



168. It must be borne in mind that, in all experiments in which the object is to ascertain the specific gravity of bodies as compared to water, the latter must be distilled, and of the temperature of 60° Fahrenheit. For as that fluid expands with every increment of temperature above 40° Fahr., it follows that very erroneous results will be obtained unless the water used in determining the densities of bodies be accurately of the temperature of 60° Fahr. And if this be not practicable, a correction must be made by calculation, so as to reduce the results obtained to the generally assumed standard. For this purpose, the following table, exhibiting the specific gravity of water for every temperature from 37° to 80° Fahr., will be found of great service.

Tem.	Sp. Gr.	Tem.	Sp. Gr.	Tem.	Sp. Gr.	Tem.	Sp. Gr.
37	1.00093	48	1.00076	59	1.00008	70	0.99894
38	1.00094	49	1.00072	60	1.00000	71	0.99882
39	1.00094	50	1.00068	61	0.99991	72	0.99869
40	1.00094	51	1.00063	62	0.99981	73	0.99856
41	1.00093	52	1.00057	63	0.99971	74	0.99843
42	1.00092	53	1.00051	64	0.99961	75	0.99830
43	1.00090	54	1.00045	65	0.99950	76	0.99816
44	1.00088	55	1.00038	66	0.99939	77	0.99802
45	1.00086	56	1.00031	67	0.99928	78	0.99788
46	1.00083	57	1.00024	68	0.99917	79	0.99774
47	1.00080	58	1.00016	69	0.99906	80	0.99759

To ascertain the true specific gravity of any body which has been weighed in water of any temperature above or below 60° Fahr., we have only to multiply its specific gravity as found by experiment, by the specific gravity of water at the temperature at which it was employed.

Ex. A substance was weighed in water at the temperature 42°, and its specific gravity found to be 5·20. Thus its true gravity, at the temperature of 60°, will be

$$5{\cdot}20 \times 1{\cdot}00092 = 5{\cdot}204784.$$

169. The specific gravity of a gas is ascertained in a similar manner to that of a liquid (166), only the standard of comparison is changed, atmospheric air being here assumed as unity, or, to avoid decimals, 1000. Let a copper or glass flask, furnished with a good stop-cock, be weighed when filled with air, and then after being exhausted by means of an air-pump as perfectly as possible (192); the difference of these weights will give the weight of air contained by the flask. Then fill the flask with the gas under examination, and carefully weigh it, this weight *minus* that of the flask will give the weight of the gas. The weight of the gas divided by that of the same bulk of air will give the specific gravity of the former as compared to the latter.

Ex. A glass flask, carefully counterpoised, held 5·7 grains of atmospheric air and 5·40 grains of olefiant gas; the specific gravity of the latter was therefore

$$5{\cdot}4 \div 5{\cdot}7 = 0{\cdot}982, \text{ for } 5{\cdot}7 : 5{\cdot}4 :: 1000 : {\cdot}982.$$

In examining the specific gravity of gases, they should be carefully freed from moisture by being passed over recently ignited chloride of calcium; and the results obtained corrected for temperature in the manner described in all chemical works.

170. The following questions will illustrate some practical applications of the knowledge of the specific gravities of the bodies.

A. What is the weight of a cubic inch of copper?

The specific gravity of copper being 8·90 (171), or more exactly 8,879, we have, to answer the question, to multiply this by the weight of a cubic inch of water, which at 62° is 252·458 grains: therefore, by logarithms—

$$\begin{aligned} \log.\ 253{\cdot}458 &= 2{\cdot}40219 \\ \log.\ \ \ 8{\cdot}879 &= \ {\cdot}94836 \\ \hline 3{\cdot}35055 &= 2241{\cdot}5 \text{ grains.} \end{aligned}$$

B. What is the weight of a cubic foot of marble, of specific gravity 2.838, in ounces?

The number of ounces which a cubic foot of water at 62° weighs are 997·1369691, this is generally assumed at 1000 ounces to avoid decimals, then $1000 \times 2{\cdot}838 = 2838$, the weight in ounces of the cubic foot of marble; to ascertain the *exact* weight, we may proceed thus:

$$\begin{aligned} \log.\ 997{\cdot}1369691 &= 2.99875 \\ \log.\ 2{\cdot}838 &= {\cdot}45301 \\ \hline 3{\cdot}45176 &= 2829{\cdot}8 \text{ ounces.} \end{aligned}$$

171. TABLE OF SPECIFIC GRAVITIES.

WATER = 1,000.

Metals.

Potassium	0·865
Sodium	0·973
Tellurium	6·115
Antimony	6·712
Zinc	7·100
Cast iron	7·207
Tin	7·291
Cobalt	7·812
Steel	7·816
Copper, cast	8·788
——— wire	8·879
Bismuth	9·882
Silver	10·474
Lead	11·352
Gold	19·258
Platinum, forged	20·337
——— laminated	22·069
Mercury	13·586

Organic Bodies.

Wood of Poplar	0·383
Larch	0·498
Cedar	0·561
Cypress	0·598
Lime	0·604
Ash	0·845
Beech	0·852
Oak	0·925
Cork	0·240
Ivory	1·826
Beef bones	1·656
White Wax	0·960

Inorganic non-metallic Bodies.

Agate	2·590
Amber	1·078
Sulphur, native	2·033

Glass, crown	2·488
——, flint	3·329
Rock crystal	2·653
Marble of Paros	2·838
Diamonds	3·501—3·531
Oriental rubies	4·283

Liquids.

Ether	0·715
Alcohol	0·792
Rectified spirits	0·837
Oil of turpentine	0·870
Oil of olives	0·915
Sea-water	1·026
Milk	1·030
Nitric acid	1·503
Ammonia	0·960
Sulphuric acid	1·845
Acetic acid	1·063
Oil of cinnamon	1·043
Oil of cloves	1·036

Gases.

ATMOSPHERIC AIR = 1,000.

Ammonia	0·590
Carbonic acid	1·527
——— oxide	0·972
Chlorine	2·500
Cyanogen	1·805
Hydrogen	0·069
Nitrous oxide	1·527
Nitrogen	0·972
Oxygen	1·111
Sulphurous acid	2·222
Sulphuretted hydrogen	1·180

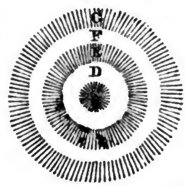
Weights of given bulks of water and air for calculating the absolute weights from the specific gravities of bodies (148):

			LOGARITHMS.
Cubic inch of distilled water (bar. 30, therm. 62)	in grains	252·458	2.40219
...... foot	in ounces avoird.	997·1369691	2·99875
	in pounds ditto	62·3210606	1·79463
Weight of 100 cubic inches of air, in grains do.		30·49	1·48416

172. Fluids are capable of assuming undulatory movements similar to the vibrations of solids (77), differing, however, in some respects, in consequence of the different physical arrangement of their atoms. If a pebble be allowed to drop in the centre of some calm piece of water, a series of ripples will be generated, diffused eccentrically from the place of impact, and becoming wider and shallower as they reach the bank. On a small scale, these are best observed by dropping a glass ball on the surface of a dishful of mercury.

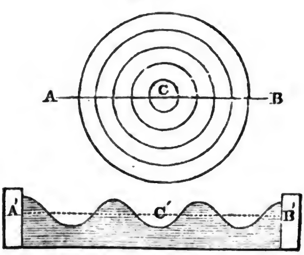
173. At the point where the pebble touches the water, a depression will be produced; this will, from the ready transmission of an applied force in all directions (145) produce a circular elevation of the water round it. The atoms of water thus elevated above their previous level will, in their turn, fall, producing a depression of the next circular series of atoms. Thus the initial motion will be gradually propagated from the point of impact, in a series of gradually widening circular ripples, until opposing causes allow the equilibrium to be regained. C will represent the depression produced by the pebble. D the elevated ripple surrounding it. E the remaining circle of depression, &c. The white circles represent the elevations, and the shaded ones the depressions of these circular waves. The particles of water are thus merely moving up and down in curves, and are not really urged from the centre to the bank of the pond or brook, although it is difficult to believe at first sight that the water does not really move laterally. This will, however, be admitted on referring to the vibrations of a rope (78), or after watching the motion of pieces of straw, &c., on the surface of water, they will move up and down with each ripple, but scarcely leave the place where first observed. These wave-like movements are not only propagated laterally, but in all other directions, as might indeed be expected, from the laws already announced (145), and extend downwards to a vertical depth equal to 350 times the elevation of each undulation.

Fig. 105.



174. An entire undulation consists, as in the case of the vibration of solids, of a phase of depression and elevation, and this may be rendered more intelligible by conceiving a series of circular undulations, divided at A C B, so as to present a vertical section. The phases of elevation and depression will present the series of curves shown by the line A' C' B'. The analogy between the undulations of fluids and vibrations of solids will thus be rendered plainer.

Fig 107.



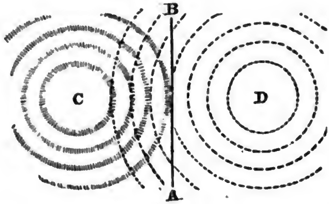
In non-elastic fluids, the attraction of gravitation (38) becomes the active agent in bringing the undulations to rest, whilst, as we have already seen, in the case of solids, elasticity produces the same result.

175. The motions of undulations, when impinging against a solid are reflected back in accordance with the ordinary laws of reflected motion.

A series of undulations, propagated from a centre C, and reaching a fixed obstacle BA, will be reflected from it in the same form and manner as if they

had been propagated from a point D, placed at an equal distance, as C, from the opposite side of the fixed obstacle. In this way, undulations generated in

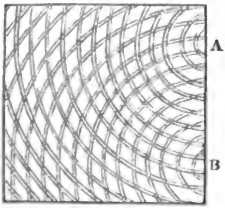
Fig 107.



the centre of a circular vessel may reach the boundaries of the fluid, and, on impinging against the walls of the vessel, be reflected back to the centre, and so on.

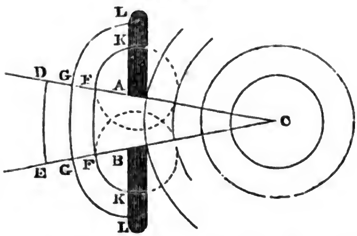
176. If two undulations meet, their resulting movement will vary according to the circumstances under which they come in contact. Thus, if two undulations in the same phase, traveling in the same direction, meet, the resulting wave will be equal to the sum of the two separate ones; but if these conditions be reversed, to their difference. Thus it is quite possible for two waves of equal intensity, traveling in opposite directions, to meet, and completely destroy each other's motion. This is termed the *interference of waves.* The two equal series of undulations, propagated from the points A and B, will, at the points where they mutually intersect, interfere and lose their motion, whilst in the intermediate spaces the water will be agitated.

Fig. 108.



177. When a series of undulations impinge upon an obstacle in which an aperture exists, those which reach the opening will pass through, the rest being reflected (175). Those which pass through, undergo a peculiar change in their curve, in consequence of striking against the edges of the opening.

Fig. 109.

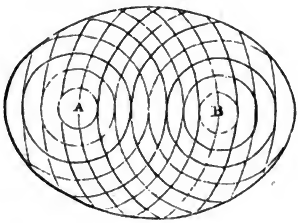


Thus a series of undulations, propagated from C and reaching the opening AB in a fixed obstacle, will be propagated through it, so as to fill the space

ABDE. The curve of the concentric waves will be altered at FFGG, &c., from the influence of the edges of the opening AB, becoming bent in the direction FK, and GE, in the direction of the arcs of circles drawn from AB respectively as centres.

177*. In consequence of the ready reflection of undulations, they may be directed in any direction by means of properly-arranged concave surfaces. In this way undulations generated in one of the foci A of an elliptic may have their conjoint effects propagated to the other, B, as shown in the subjoined figure.

Fig. 110.



CHAPTER VII.

GENERAL PROPERTIES OF ELASTIC FLUIDS (PNEUMO-STATICS.)

Composition of the Atmosphere, 178. *Finite extent of*, 179. *Weight of*, 181. *Pressure of*, 182. *Barometer*, 185, 186. *Correction for Capillarity*, 186. *Diurnal Height and horary Variations of*, 187. *Measurement of Heights*, 188. *Law of Marriotte*, 189. *Aerial pressure*, 190. *Air-pump*, 191, 192. *Condensing Syringe*, 193. *Illustrative Experiments*, 194.

178. THE great mass of gaseous matter, surrounding our earth and extending to a considerable distance from it, is termed the *atmosphere* or *atmospheric air*. This, like the denser fluids, obeys laws similar to those treated of in the preceding chapters, with such modifications as its eminently elastic character produces. Like the less elastic liquids, gases obey the attraction of gravitation (38), and the conditions of equilibrium and equal pressure (146), explained in the last chapter. Atmospheric air freed from moisture consists, in 100 parts, of

	BY VOLUME.	BY WEIGHT.
Nitrogen	79·	76·9
Oxygen	21·	23·1

A certain and variable proportion of carbonic acid and aqueous vapor, is always present in the atmosphere. As an average, it may be assumed that 1000 parts of air consist of

Nitrogen	788.
Oxygen	197.
Aqueous vapor	14·
Carbonic acid	1.

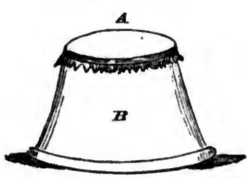
179. In consequence of the atmosphere being confined to the earth's surface by gravitation (38), we find it much denser near the level of the sea (148), than at any distance above it. As we ascend above the surface of the earth, the density of the atmosphere rapidly decreases; thus, at an elevation of 3 miles, it is $\frac{1}{2}$ the density of the air on the earth's surface; at 6 miles it is $\frac{1}{4}$; at 9 miles, $\frac{1}{8}$; and at 15 miles, $\frac{1}{30}$ of that density (188). The greatest part of the atmosphere is thus evidently always within 30 miles of the surface of the globe, although from certain astronomic phenomena, it is supposed to extend to a distance of 40 or 45 miles; and here is, in all probability, its utmost limit. Dr. Wollaston* has shown that, at this elevation, the attraction of the earth upon any one particle, is equal to the resistance arising from the molecular repulsive power of the medium. Another proof of the finite extent of the atmosphere is found in the fact of the sun, and the planets, being destitute of any similar media surrounding them; for if it is supposed to extend into infinite space, such large masses of matter as the planets, must surely have caused a considerable portion to gravitate towards them. Other philosophers† have supposed that the extreme cold of the upper regions is sufficient to prevent the infinite expansion of the atmosphere. Dr. Dalton,‡ reasoning on one of Newton's propositions,§ has adopted the opinion of Wollaston.

180. The extreme elasticity of gaseous substances arises from the intensity of their molecular repulsion, which, instead of being nearly equally balanced, or exceeded, by the intensity of molecular attraction, as in solids and liquids (8); tends continually to separate the atoms still further from each other, and to press against the sides of a vessel containing them with sufficient force to rupture it, if sufficiently weak, were this effect not checked by external pressure (194, D). Unlike the far less elastic liquids, gases never present a level surface free from pressure, for they tend continually to expand themselves into space, to prevent which, actual force must be exerted.

181. The weight of 100 cubic inches of atmospheric air, at 60° Farenheit and the barometer at 30 inches, has been computed at 30·92 grains, by Kirwan; at 31·10, by Sir H. Davy; at 30·5, by Sir G. Shuckburgh; and at 30·199, by Mr. Brande.

182. The atmosphere presses upon all bodies immersed therein with very considerable force,—a force which would be sufficient to crush animal structures, if, in obedience to the laws of equal and contrary pressure (152), this effect were not prevented. Let a piece of bladder be firmly tied over the end A of the strong glass vessel A B, it remains perfectly flat, and gives no evidence of any force pressing upon it, for the reasons above stated. Then place the lower part of the vessel on the plate of the air-pump, and exhaust the air from beneath the bladder (192); the upward pressure (195) which prevented the weight of the atmosphere from exerting its effect becomes removed, the bladder curves inwards under its influence, and at last gives way with a loud report.

Fig. 111.



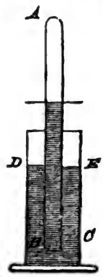
* Phil. Trans. 1822, p. 90.
† Phil. Transactions, 1826.
‡ Phil. Trans. 1823.
§ Principia, Book ii. prop. 2., p 292.

If a plate of glass were placed on A, instead of the bladder, it would, if sufficiently thin, become broken by the pressure of the atmosphere. This pressure is, in round numbers, equal to fifteen pounds upon each square inch of surface (190).

183. Atmospheric pressure is exerted upon everything on the surface of our globe, nothing is naturally exempt from its influence, any more than from gravitation, to which force this pressure is indebted for its origin (180).

If a tolerably wide glass tube A B be partly filled with water and inverted in the vessel C, filled also with water, the fluid will not fall in the tube but remain suspended at a higher level than that of the external portion, in appearance contrary to the force of gravitation, of which it is, however, the simple effect. For the atmosphere, pressing upon the surface D E of the water in C, acts upon that in A, and keeps it elevated in the tube; for the opposing pressure necessary for its equilibrium, is cut off by the end A being closed. But if we perforate the upper extremity of the tube, the pressure of the air becomes equally exerted on the water in A and C, and accordingly in each it acquires the same level. If the tube A B be of any length under about thirty-three feet, the pressure of the atmosphere upon the surface of the fluid in which its open end is immersed will be sufficient to keep it full of water, when it had been previously filled with, and inverted in, a cistern full of that fluid.

Fig. 112.



184. If, instead of filling and inverting the tube, the upper end be connected with a good exhausting pump or syringe, and the air in its interior removed, the pressure of the atmosphere upon the water in the cistern, in which its lower end is immersed, will force that liquid into its interior, up to a certain elevation, averaging about thirty-three feet.* At this elevation, the column of water becomes balanced by the pressure of the atmosphere; and, of course, any change in the pressure of the latter will be attended by a corresponding change in the elevation of the water in the tube, forming *a barometer*, or measurer of aerial pressure. An instrument constructed in this manner, has been erected in the hall of the apartments of the Royal Society, and its indications are highly interesting and delicate. Water barometers, in consequence of their length, are extremely inconvenient, and accordingly the mercurial barometer is universally employed.

Fig. 113.

185. Mercurial barometers are constructed on the same principles as the water barometer, but the tube being filled with a fluid 13.58 times heavier than water, is required to be but $\frac{1}{13.58}$ times as long as that of the water-barometer. A column of mercury, thirty inches in height, exactly counterbalancing, at average pressure, the downward force of a column of atmospheric air of the same diameter. To construct a mercurial barometer, select a glass tube A B, about thirty-two inches in length, and fill it carefully with very pure mercury; then, closing the end B, with the finger, immerse it in the vessel of mercury C. On removing the finger, the mercury in A B will fall to a certain distance, leaving a column, in the tube, of a height corresponding to the atmospheric pressure at the time.

* Boyle's works: Dr. Shaw's edition, 1725, vol. ii. p. 486.

The space above DD, unfilled with mercury, is the nearest approach to a perfect vacuum which can be procured by art; for, on depressing the end B deeper in the mercury the whole tube becomes completely filled; the fluid metal again falling on elevating the tube. The space above DD contains a small quantity of mercurial vapor, and is termed the Torricellian vacuum, from its having been first observed in 1643 by Torricelli, a pupil of Galileo. The height of the mercury in the tube, is always measured from the surface of that in the cistern C; and this elevation is the measure of atmospheric pressure at the time. The elevation assumed as the standard in this country is thirty inches, and to this, all measurements and weights of gaseous bodies are referred.

Several modifications of the barometer are in use, as the syphon, and wheel barometers; their theoretical action is the same as that of the straight tube above described. In the construction of these instruments, great care is required in freeing the mercury from air; this is best effected by boiling the fluid metal, and introducing it into the tube whilst warm.

186. When it is required to make very accurate observations on the pressure of the atmosphere as indicated by the length of the column of mercury in the barometer; care must be taken to make certain corrections for the temperature of the air as influencing the expansion of the mercury. On this account all accurately reported barometric observations are supposed to be made at a fixed temperature, which is generally that of freezing water, 32° Fah. To correct a barometric observation for the dilatation of the mercury by the heat of the air, we must bear in mind that this metal dilates $\frac{1}{10000}$ of its bulk for every degree of Fahrenheit's thermometer above 32°. If then we subtract the ten-thousandth part of the observed altitude of the mercurial column, for every degree by which the temperature of the mercury is above 32°, we shall have the true height of the column at a freezing temperature. This correction for an observed elevation of 30 inches at a temperature of 59° is ·054 of an inch.

The capillary repulsion (25), by depressing the surface of the mercury, is another source of error, and must be allowed for in the estimation of the height of the barometer. This increases with the decrease in the diameter of the tube. Its amount is shown in a table already given (31).

187. To obtain accurately the mean diurnal height of the barometer it is necessary to observe the height of the column of mercury every hour, during twenty-four hours, and to take the mean of these observations. This tedious process can, to a great extent, be avoided; for a French philosopher, M. Ramond, has proved that at noon, the elevation of the mercury corresponds almost exactly with the mean diurnal height.

The column of mercury, in the barometer, undergoes several regular variations in the course of the day; they are termed *horary variations*. From the observations made at the equator by Baron Humboldt, the maximum elevation takes place at nine o'clock in the morning; past this hour it becomes less, until four, or half-past four in the afternoon, when it attains its minimum; it again ascends until eleven at night, when it reaches its second maximum; and once more descends to four o'clock in the morning, after which it reascends until nine. Thus every day, the mercurial column is at its lowest elevation at four in the morning and afternoon, and at its greatest, at nine in the morning and eleven in the evening. The amplitude of these variations is but small, being calculated by Humboldt at only 0·07874 inch. In Europe, these horary variations become masked by changes of atmospheric pressure, depending upon accidental causes, which, at the equator, are nearly without action on the barometer. As far as these horary variations have been observed in our northern latitudes, the maximum in winter appears to be at

nine in the morning, the minimum at three in the afternoon, and the second maximum at nine in the evening. In the summer, the maximum elevations are at eight in the morning, and eleven at night; the minimum being at four in the afternoon. In spring and autumn, the times of these variations are intermediate with those of summer and winter.

188. Among many important uses of the barometer, must be mentioned its application for the purpose of measuring heights. As we ascend from the level surface of the earth, the column of atmosphere, pressing on the mercury, becomes virtually shorter, and consequently the fluid metal falls in the tube.

The increase of rarity of the air, as we ascend above the surface of the earth, has been already mentioned (180); the following is a view of the corresponding subsidence of the mercury in the barometer, at several elevations.

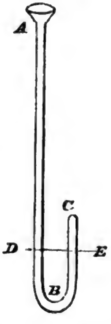
At the level of the sea, the mercury stands at 30 inches,

5,000 feet above	24·797
10,000	15·000
15,000	16·941
3 miles above	15·00
6	7·50
9	3·75
15	1·00

Hence the subsidence of mercury in the barometer, as we ascend mountains or other elevations, affords valuable data for calculating their vertical height.

189. From the density of the atmosphere diminishing as we recede from the earth, we learn that gases increase in volume, as the force acting upon them diminishes in intensity. This has been long recognized as the *law of Marriotte*, and is concisely stated thus: "*the volumes of gases are in the inverse ratio of the pressures which they support.*" The truth of this is readily demonstrable: let some mercury be poured into a glass tube ABC, having its end C carefully closed and by gently inclining it, let the fluid metal flow into the shorter leg, until it stands at the same level in both, as up to the dotted line DE. The space CE will, consequently, contain a certain bulk of atmospheric air, submitted to the ordinary pressure of the air through the open tube A. To compress this air into one-half its volume, pour mercury into A, until it stands at an elevation above the line DE, equal to the height of the barometer at the time; the air in C will thus be submitted to a pressure equal to that of two atmospheres; one, of the atmosphere itself pressing on the mercury in A; the other, of the column of mercury in the tube above D, which in an average state of atmospheric pressure will be 30 inches in length (185), and therefore, equal to the pressure of one atmosphere; and accordingly the air in C becomes compressed to half its original bulk. This law has been verified under a pressure of twenty seven atmospheres. A necessary consequence of the law of Marriotte is, that *the density of gases is in proportion to the pressure to which they are exposed;* and consequently, under a pressure of 770 atmospheres, air would become as dense as water.

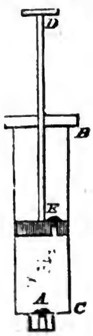
Fig. 114.



190. In consequence of the atmosphere, in average states, being capable of supporting thirty inches of mercury, it is easy to calculate the pressure upon each square inch of surface exposed to its action, by ascertaining the weight of a column of mercury thirty inches high, and one inch square. This will

be found to be very nearly equal to fifteen pounds, which is therefore assumed as the amount of pressure on every square inch of surface exposed to the atmosphere. This pressure corresponds very nearly, to that of a column of atmospheric air five and a quarter miles in length, if of uniform density; but, as this diminishes in proportion as we rise above the level of the sea, the air really extends to a much greater elevation (180). If the surface of an adult be considered as equal to 2000 square inches, the pressure exerted on his body by the atmosphere, is equal to the enormous amount of 30,000 pounds or nearly 14 tons, a force more than sufficient to crush him to atoms, were it not opposed by the equal and contrary pressure of the aeriform and other fluids conveyed in the cavities of his frame.

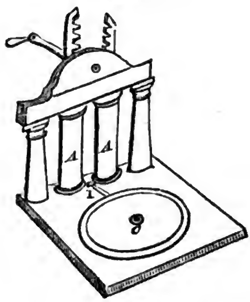
Fig. 115.



191. For the purpose of examining the effects resulting from atmospheric pressure, an exhausting syringe, or air-pump, becomes a necessary piece of apparatus. These instruments are constructed on the same principles: the former consists of a barrel, BC, of metal, furnished with a screw at C, for the purpose of connecting it with any apparatus required; at A is a valve, opening upwards. The piston ED moves air-tight in the barrel, perforated at E, and there furnished with a valve, also opening upwards. Connecting this syringe, by means of the screw C, with any piece of apparatus, let E be drawn up to B by raising the handle D, and then depressed; the air inclosed between E and A will escape through the valve E; on again elevating the piston E, a vacuum is formed between E and A; air rushes in through A, to fill it; and on again depressing the piston, this escapes through the valve E, and so on. The air in the vessel connected with C, becoming each time more rarefied, and ultimately affording an approach to a vacuum.

192. As this process is extremely tedious, and in proportion as the air becomes more rarefied, the external atmosphere, pressing on the piston, renders it laborious to elevate it,—this syringe has given way to the air-pump, constructed with two similar barrels, connected by a tube with a perforation in the centre of a smooth plate of brass, on which strong glass vessels, called

Fig. 116.

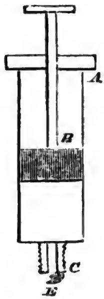


receivers, are fitted air-tight. By working the pistons, by means of a cog-wheel and rackwork, the labor of exhaustion becomes much diminished. AA are the two barrels communicating by the tube I, with the aperture C, in the centre of the air-pump plate. In the earlier machines, the barrels were

connected directly with a large glass globe, in which the substance to be experimented upon was placed.*

As by means of these instruments, the air, in a vessel connected with them, is only excessively rarefied, never becoming a *perfect* vacuum, it is frequently a matter of importance to measure the degree of rarefaction of the included air; for this purpose the open top of a barometer tube is connected with the tube I, its lower end being plunged in mercury. On placing a receiver over C, and exhausting the air, the mercury is forced up into the tube by the pressure of the atmosphere; and the nearer its height corresponds to that of the barometer at the time of the experiment, the nearer the air in the receiver approaches to a state of perfect exhaustion. Another mode of gauging the degree of exhaustion is, by immersing the end of a tube, eight inches in length, in a little vessel of mercury, with which the tube itself has been previously filled; on placing this under the receiver on the air-pump plate, and exhausting the air, the mercury beigins to fall in the tube when about one-fourth of the whole air in the receiver is removed, and by its continuing to subside, as rarefaction proceeds, informs us of the degree of exhaustion.

Fig. 117.



193. When the density of the air is required to be increased, the condensing syringe, the converse of the exhausting syringe (191), is employed. This consists of a brass barrel, furnished at E with a valve opening downwards; a perforation is made in the side of the barrel at A. On screwing this syringe on a strong metallic vessel, and raising B above the opening at A, all the space between B and E becomes filled with air, and, on depressing the piston, this is forced through the valve E, into the vessel screwed on C. On again raising B, air cannot escape through E, because the valve opens downwards; and on depressing the piston, a fresh portion is forced through E into the vessel, and thus the condensation of several volumes of air into a small bulk becomes effected.

194. By means of these machines, many highly interesting experiments, illustrating the general properties of the gaseous bodies, may be performed. The following are examples of these:

Illustrating Atmospheric Pressure.

(A.) Place in close contact, the two brass hemispheres AB, and connect them, by means of the screw C, with the hole in the centre of it in the air-pump plate (196); exhaust the air from their interior, close the stop-cock E, remove them from the air-pump, and screw on the handle F. On then attempting to forcibly separate A from B, it will be found nearly impossible, by any moderate exertion of strength, to effect this: for they will be pressed together by as many times fifteen pounds as there are square inches on the surface. This apparatus is well known as the Madgeburg hemispheres, from its having been invented by Otto de Guericke, burgomaster of that town.

(B.) Pour some mercury into the cup A, excavated in the substance of a piece of wood screwed on to the top of the receiver B, and place the whole on the air-pump plate. On exhausting the air from B, the mercury will be forced through the pores of wood into the receiver B, in the form of a metallic shower, by the pressure of the external atmosphere.

* Boyle's Works, vol. ii. p. 403.

Fig. 118.

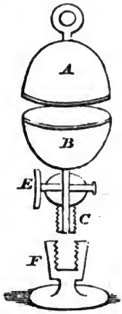
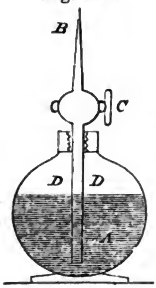


Fig. 119.

Illustrating the Elasticity of Air.

(C). Remove the jet B, from the vessel A, and screw on the condensing syringe (192), having previously half filled A with water; on forcing air into this vessel, it will bubble up through the water, and rise on its surface DD. After working the piston for a few minutes, close the stop cock C, remove the syringe, and screw on the jet B. The condensed air will press upon the surface of the water in A; and on opening the stop-cock, will force it out in a jet, forming a fountain often rising to a very considerable elevation.

Fig. 120.



(D). Press together the sides of a bladder, so as to nearly empty it of air, and tie it tightly at the neck; place it under a receiver on the air-pump plate, and exhaust the air; as soon as the pressure of the latter becomes removed from the surface of the bladder, the elasticity of the small quantity of air left in it comes into play, and, expanding according to the law of Marriotte (159), forces the sides of the bladder asunder, and expands it. On readmitting air into the receiver, the small quantity left in the bladder contracts to its former bulk; and causes it to appear as empty as at first.

(E). Place a vessel of spring water under the receiver of the air-pump, and exhaust the air; as soon as the pressure of the atmosphere becomes removed, the air dissolved in the water expands by its elasticity, forms large bubbles, and escapes from the water, giving to the latter the appearance of being in a state of slow ebullition.

(F). On placing baked apples, raisins, or shrivelled fruit, under the receiver of an air-pump, and removing the pressure of the atmosphere, the air they contain expands, and dilating the integuments of the fruit, gives them the appearance of ripe plumpness. On readmitting air into the receiver, this artificial and delusive appearance vanishes, and the fruit appears as shrivelled as before the experiment.

(G). Place a glass vessel half full of hot water under the air pump receiver; as soon as the air is exhausted, the water will begin to boil violently, and rapidly evaporate, to fill the partial vacuum produced by the exhaustion of the air in the receiver (697).

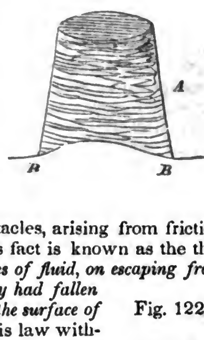
CHAPTER VIII.

GENERAL PROPERTIES OF ELASTIC AND NON-ELASTIC FLUIDS. (HYDRO- AND PNEUMO-DYNAMICS.)

Pressure against the sides of vessels, 195. *Theorem of Torricelli*, 196. *General law of Currents*, 197—*lateral Reaction of*, 198. *Velocity of Fluid through Narrow Channels*, 199. *Fountains*, 200. *Friction between Fluids and Solids*, 201,—*between Fluids only*, 202. *Properties of Gaseous Currents*, 203. *Aerial current and winds*, 205. *Waves or Undulations of Air*, 206, 207—*Reflexion and Interference of*, 208. *Pumps*, 210—*Syphons*, 213—*Hiero's Fountain*, 215—*Hydraulic Press.*

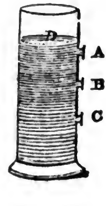
195. When a liquid, as water, is contained in any vessel, the sides of the latter become submitted to the influence of two opposed forces, one acting from without to within, and the other in the converse direction. The internal pressure arises from the weight of the column of fluid pressing against the sides (154), and the external force is the pressure of the medium in which the vessel is immersed. If an opening be made in the side of a vessel so circumstanced, the surface of the fluid thus exposed is still acted upon by the same forces as had previously pressed against the portion of the side removed. If the pressure from within to without be greater than the pressure in the opposite direction, the fluid will flow out of the opening, and, obeying the force of gravitation, fall to the earth. But if the external pressure is the most powerful, the fluid will not escape. This may be illustrated by filling a glass tumbler, A, with water, placing a piece of paper, B B, over its mouth, and carefully inverting it. On holding it in this direction, the fluid will not escape, for the upward pressure of the atmosphere against the paper will exceed the action of the attraction of gravitation on the water and accordingly the glass will remain full.

Fig. 121.



196. Liquids, escaping from orifices in vessels containing them, obey the force of gravitation, and their motion becomes accelerated in a corresponding manner, providing all mechanical obstacles, arising from friction or other causes, be absent. The expression of this fact is known as the theorem of Torricelli, and may be thus stated: *particles of fluid, on escaping from an orifice, possess the same degree of velocity as if they had fallen freely, in vacuo, from a height equal to the distance of the surface of the fluid above the centre of the orifice.* Fluids obey this law without any relation to their density, their velocity solely depending upon the depth of the orifice from which they escape, below the level of the fluid. Thus, if a vessel be filled with water to the height of the dotted line D, and three apertures be made in the side of the vessel at A B C, the water will escape from each with very different velocities. At A, it will possess the same velocity as if the particles of water had fallen in vacuo from D to A, whilst at B and C the escaping current will possess the same velocity as if the fluid composing it had fallen from D

Fig. 122.



to B and from D to C. From this fact we learn that two vessels perfectly alike, being filled with fluid, and allowed to discharge a certain measure by similar orifices, *one of them being kept quite full by the addition of fresh fluid*, the quantity of water discharged in a given time from the latter vessel, as compared with the quantity escaping from that which was allowed to empty itself, will be as 2 to 1.

The velocity of fluids thus escaping from orifices is, *cæteris paribus*, as the square roots of the depths of the orifices below the surface of the fluid. Thus calling the velocity of a fluid, escaping from an orifice one foot below the surface, unity: the velocity of a fluid, escaping from a similar orifice 4 feet below the level, will be 2; at 9 feet 3; at 16 feet 4, and so on.

197. When fluids escape from lateral apertures, they describe parabolic curves, and obey the laws of projectiles (93); and when allowed to escape through a circular orifice pierced in the bottom of a containing vessel, providing the latter be composed of some very thin material, the following phenomena are observed:

(A.) The particles of fluid descend vertically, to within three inches of the bottom, and then turn towards the orifice.

(B.) The surface of the fluid gradually falls, remaining horizontal until within a certain distance of the bottom, when it forms a hollow cone, immediately above the centre of the orifice.

(C.) The current of fluid having escaped from the vessel, contracts in diameter at a certain distance from the orifice.

(D.) When a fluid escapes from an orifice made in the thin side of a vessel, the greatest contraction of the fluid vein takes place at a distance from the orifice equal to half its diameter; the diameter of the contracted portion of the vein being to that of the portion nearest the orifice as 5 : 8.

(E.) Beyond this contraction (D) the liquid vein continues to *diminish* in thickness, if moving from above to below, and to *increase*, if moving in the opposite direction.

(F.) The surface of a fluid escaping by a *lateral* aperture does not form a hollow cone (B), but becomes depressed on the side in which the orifice exists.

(G.) Every fluid vein, moving vertically downwards from a circular orifice, is composed of two well defined portions. The portion nearest the orifice is perfectly transparent, like a rod of glass or crystal; its section is circular, and it gradually decreases in diameter, until it joins the second portion of the current, which is nearly opaque, and apparently much agitated, consisting of a multitude of drops, each produced by an annular dilatation of a portion of fluid at the orifice of the vessel, and undergoing, during the time of its falling, a series of periodic vibrations, by which each drop alternately elongates and contracts. A series of pulsations thus occur at the orifice of the vessel, their number being in the direct ratio of the rapidity of the current, and in the inverse ratio of the diameter of the orifice; they are frequently sufficiently rapid to produce a distinct musical sound (218).

(H.) In consequence of the contraction of the fluid vein (C) (D), liquids escape with equal rapidity from a conical tube, as from a cylindrical one of equal length, providing the truncated apex of the former corresponds in situation and section, to the point of *greatest contraction* of the fluid current.

198. In a vessel full of water, the downward pressure of any column of fluid, as AB, pressing on the horizontal layer CD, acts with a certain degree of force on the sides of the vessel (154); if then, an aperture be made at C, the pressure there becomes null, and fluid escapes, whilst the pressure remains active at D. As the pressure of BC against the side is removed, and that against BD continues in action; the vessel, if carefully suspended, will move as if repelled in a direction opposed to that of the current escaping from C.

Fig. 123.

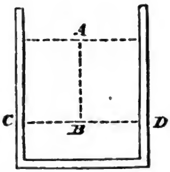
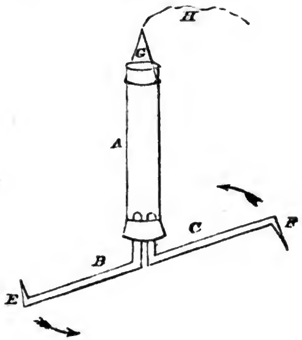


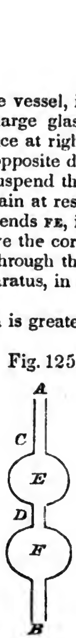
Fig. 124.



The movement arising from this reaction against the sides of the vessel, is readily illustrated by means of the apparatus ABC, consisting of a large glass tube, A, closed at both ends with corks; two tubes, CB, bent twice at right angles, are fixed in the lower cork, their ends at EF being bent in opposite directions. Fill A with water, place the cork G in its place, and suspend the whole, by the thread H, from the ceiling. The apparatus will remain at rest, for no fluid can escape, as the pressure of the air against the open ends FE, is more intense than the gravitation of the fluid (195). Then remove the cork G; the atmospheric pressure will act on the water in A, forcing it through the tubes BC, and escaping at FE, producing a rapid rotation of the apparatus, in a direction contrary to that of the current of escaping fluid.

199. When fluids pass through a tube, or channel, whose section is greater at one part than another, the velocity of the liquid is necessarily greater in the narrow, than in the wide parts, as the same quantity must pass through every part in the same time. Thus, if in the tube AB, water be allowed to run through in a stream, so as to keep it constantly full, its velocity at CD will be much greater than when traversing the wide parts, EF. The momentum of the fluid will be equal in every part; for as it is equal to the quantity of matter multiplied by the quantity of motion (71), although the quantity of fluid contained in CD, is less than in EF, yet its velocity is proportionably greater. For the same reason, when water flows through a funnel, its velocity is much greater when passing through the tube than when traversing through the wider part of the instrument; and hence, also, the current of rivers is more rapid under the arches of bridges than at any other part.

Fig. 125.



200. Springs and fountains are formed by some concealed reservoir of water escaping through a cleft, or fissure, in the rocks containing the supply of fluid. On the water escaping, it possesses a velocity regulated according to the theorem of Torricelli (196), and therefore sufficient to project it upwards in the form of a jet d'eau. Artificial fountains are constructed on a similar principle; thus, if the tube AC be filled with water, it will escape from the aperture at C, in a jet rising to an elevation somewhat less than that of the column of water in A; according to the experiments of Marriotte, at-

Fig. 126.

taining an elevation of 5 feet, if the column of water in the reservoir be 5 feet 1 inch high. The elevation of the jet d'eau would be equal to the height of fluid in the reservoir, if all friction from angular bends or projections, &c., as well as the resistance of the atmosphere, were removed (42). The greatest elevation, *cæteris paribus*, is obtained when the fluid escapes through an aperture pierced in a thin plate of metal, avoiding all conical terminations, or *ajutages*.

201. Friction is found to take place between solids and liquids, and even between the particles of fluids themselves. A stream of water is always more rapid in the centre than at the sides, as, being deeper there, the current flows on the surface of lower strata of fluid; whilst, in the shallower portions of the river, the water is exposed to the friction of the rough and unequal bottom. In the centre, also, the stream is somewhat more elevated than at the sides; as in its rapid course, it draws the water from the sides of the river after it, by the friction of its particles.

In the *ajutage*, or escape-pipe, of a fountain, a similar fact is observed; for if it be bent abruptly, and not with a regular and gradual curve, the passage of fluid becomes much obstructed. Thus, fluids escaping under equal pressures, will rise much higher if passing through the tube A than through B.

Fig. 127.

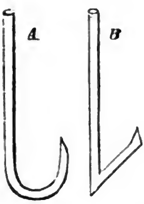


Fig. 128.

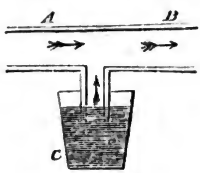
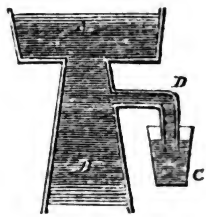


Fig. 129.



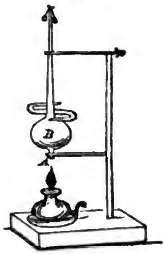
202. The friction of (fluid) particles is illustrated by an experiment of Bernouilli: he found that water, in passing rapidly from the narrow to the wide end of a conical tube, AB, would empty the vessel C, filled with water and communicating with AB, by a small lateral tube. Dr. Barry found that a similar effect was produced by a descending current; for when water was allowed to flow rapidly from A to B, a vessel, C, communicating with AB, by the tube D, became rapidly emptied.

In the circulating system of animals, an arrangement of the blood-vessels is frequently observed in accordance with these principles, so that a current of blood passing along one vessel, may assist in emptying a lateral branch; or two currents entering a larger trunk at the same point, may thus exhaust the contents of a small vessel entering between them. In the human body, the termination of the left spermatic vein in the renal vein, and that of the thoracic duct in the angle formed by the internal jugular and subclavian veins affords remarkable examples of such hydraulic arrangements in animal structures.

203. Elastic fluids, or gases, offer no important exceptions to the above laws; in escaping from lateral orifices, they produce a similar reaction against the opposite side, and corresponding tendency to motion, as in the case of

denser fluids (198). This may be illustrated by a very common toy, now made by all glass-blowers, consisting of a globular vessel B of thin glass, resting on a pivot at A. From the opposite sides of the vessel proceed two tubes, bent at right angles near their terminations. When a little water is placed in the vessel, and heat applied by means of a spirit-lamp, it will become converted into steam, and give to the apparatus, on escaping from the lateral tubes, a rapid rotatory motion. In the opinions of most philosophers, elastic fluids also appear to obey the conditions of the theorem of Torricelli, when escaping under the influence of pressure* from orifices, unless the difference between the external and internal pressure be very considerable, in which case they offer some exception to this law (196).

Fig. 130.



204. It is also extremely probable that, like denser fluids, gases undergo, when escaping from apertures, a contraction in the diameter of the current; the area of the section of this contraction appears to be equal to that of the orifice through which the gas is escaping, multiplied by the decimal 0·61 or 0·62.

One very remarkable phenomenon, connected with the escape of a current of air under considerable pressure, must not be passed over silently. M. Clement Desormes† has observed, that, when an opening, about an inch in diameter, is made in the *side* of a reservoir of compressed air, the latter rushes out violently; and if a plate of metal or wood, 7 inches in diameter, be pressed towards the opening, it will, after the first repulsive action of the current of air is overcome, be apparently attracted, rapidly oscillating within a short distance of the opening, out of which the air continues to emit with considerable force. This curious circumstance is explained on the supposition, that the current of air, on escaping through the opening, expands itself into a thin disc, to escape between the plate of wood or metal, and side of the reservoir; and, on reaching the circumference of the plate, draws after it a current of atmospheric air from the opposite side, in a manner, probably, analogous to the case of friction between particles of liquids already described (202). The plate thus balanced between these currents remains near the aperture, and apparently attracted by the current of air to which it is opposed.

205. When the air is made to assume motion, the currents produced are denominated winds, and are tolerably uniform for a given space. The following table‡ gives a view of the rapidity of currents producing winds of various forces:—

Rapidity of motion per second.	
1·64 feet. . .	scarcely perceptible wind.
3·18 — . . .	sensible breeze.
6·56 — . . .	moderate wind.
18·04 — . . .	brisk wind.
32·80 — . . .	strong wind.

* The following formula is Bernouilli's expression for the velocity of an escaping gas:

$$v = \sqrt{2k\frac{(p-p')}{p}}$$

v = velocity of the gas; p = internal, and p' = external, pressure; and $2k$ = a co-efficient equal to 155610 for gases at the temperature of 32° Fahrenheit.

† Annales de Phys. et Chim., xxxvi. p. 69.

‡ Ann. de bureau des longitudes pour 1828.

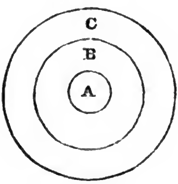
12

65·70 feet . . . violent wind.
73·80 — . . . tempest.
88·56 — . . . violent tempest.
118·08 — . . . hurricane.
147·60 — . . . violent hurricane, sufficiently powerful to tear up trees and produce the most violent mechanical effects.

Marriotte has shown that a wind moving at the rate of 12·78 feet per second, impinges against a surface of 395·67 square inches with a force equal to 2696 grains, or more than 5½ ounces.

206. When elastic fluids or gases, as atmospheric air, are submitted to mechanical force, they are capable of assuming certain alternating movements, analogous to the vibrations of solids and undulations of water (77, 171), and other non-elastic fluids. These motions of gases differ, however, in some particulars, from those assumed by water, in consequence of their physical condition, their components being held together with a very weak attractive force (8). Suppose a certain amount of force of momentary duration be applied to a particle of air A. Under its influence, its atoms for a moment fly asunder, and the particles dilate equally in all directions, so as to fill a larger space, as B. Now in thus expanding from A to B, it follows that the air previously contained in the space AB must be driven off. Now its *inertia* (41) opposes an obstacle to this taking place; it accordingly becomes momentarily condensed, its atoms approximating under the influence of the expanding force of A. The particle A then contracts, but its elasticity again causes it to dilate, and these alternations continue until the effects of the applied force are lost, and the particle A obtains its state of rest. The concentric portion of air B, compressed under the influence of A, in its turn, dilates and acts on a shell of air external to it; this, in its turn, on another, and so on; thus the initial force acitng on A, exerts its influence on concentric portions of air, its effects becoming less marked with each, until it becomes too feeble to produce any effect on more distant portions, as in the case of the ripples of water (173).

Fig. 131.



207. In the case of these *oscillations*, *undulations*, or *pulses* of air, it is obvious that we must regard them as extending equally in all directions in the free air, and limited only by the shape of the containing vessel when the air is confined in small spaces. Therefore the effects of the united oscillations or pulses extend equally in the course of radii from a centre to every point of the surface of a sphere.

In these aërial undulations, on referring to the last figure, it is obvious that the portion of air A will have expanded to B, and contracted to its smallest limit at the moment that B attains its greatest dilatation. The space from the centre of A to the surface of B is termed a wave, and a line produced from A to B will represent the length of the wave, undulation, or pulse.

208. The remarks made on the reflection, transmission, and interference of undulations of non-elastic fluids, equally apply to the elastic fluids or gases. Two waves of air moving in the same direction will exert an influence on surrounding air equal to their sum, and if in opposite directions, to their differences. We shall have, however, again occasion to return to this subject when treating of the oscillations of ether (552), in explanation of the theory of light and heat.

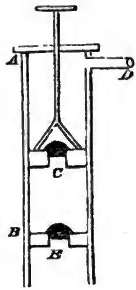
209. The applications of the physical properties of fluids to the purposes of domestic economy, and the wants of civilized life, are extremely important, and afford some important objects of study to the mechanic and engineer. An

outline of the mode of action of a very few of these valuable presents of science to art, will not be misplaced in this chapter, as they will afford an opportunity of explaining their mode of action to the student, on the principles already laid down.

210. Among the various instruments used to elevate fluids above their former level, those termed *pumps* are the most important. Their theoretical construction is extremely simple: they may be divided into two chief sections; the first including the sucking and lifting; the other, the forcing pumps.

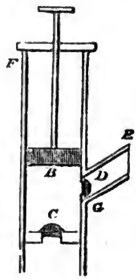
The sucking or suction pump, as it is incorrectly termed, consists essentially of a hollow cylinder AB, having a valve E, opening *upwards*, fixed in its lower extremity. A piston C, furnished with a valve, also opening upwards, moves in the interior of the cylinder. If the lower end of the pump be immersed in water, and the piston be depressed to E, the air between CE will escape by the valve in C, and on elevating the piston, a partial vacuum is formed below C; which the water rushes in, through E, to supply. On once more depressing C, this water elevates the valve in the piston, and passes through it, so that on again elevating C, a column of water is raised with it, which eventually escapes through the side tube, or sprout D. On thus continuing alternately to raise and depress the piston, water may be raised from the reservoir in which the lower end of the pump is placed. The action of the lifting pump is so similar, that a distinct account of it is unnecessary; as usually constructed, it differs chiefly, from the pump just described, in the piston entering the cylinder from below, instead of from above.

Fig. 132.



211. The forcing pump differs from the last in the position of its valves: the piston B moving air-tight in the cylinder FG, as in the sucking pump, but has no valve. A valve opening upwards is fixed in the lower part of the cylinder; and at G, a lateral tube, GE, is fixed, having a valve, D, opening upwards. The *rationale* of the action of this apparatus is very obvious: on B being depressed to C, the air is forced through the valve D; and if the pump has its lower end plunged in water, on raising B, the fluid will rush through C, to supply the partial vacuum thus formed. And on depressing the piston, this portion of water will be forced through the valve D out of the side tube GE, as, in consequence of the valve C opening upwards, it cannot escape downwards.

Fig. 133.

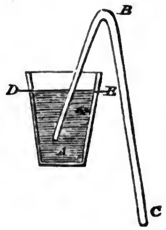


212. The most valuable acquisition to modern medicine, the well-known stomach-pump, is an instrument of this description; the tube introduced into the stomach being alternately connected to the lower end, or the side tube E, according as it is required to inject fluid into, or to empty the contents of the stomach. A glance at the construction of these pumps will be sufficient to point out their similarity to the air-pump (192). In the ordinary pump, on raising the piston, water instead of air rushes in, and, on that account, the valves do not require that excessive care in their construction, which is necessary for the proper action of a good air-pump.

In all kinds and modifications of pumps, or other instruments by which water is raised above its former level by means of atmospheric pressure, it must be recollected that they are limited in action to a distance of about 32

or 33 feet (184), above the level of the water they are acting upon, as a column of water of that length is very nearly equal in weight to the pressure of the atmosphere.

Fig. 134.



213. The well-known hydraulic instrument, the syphon, consists, in its simplest form, of a bent tube, ABC, having one of its branches longer than the other. On immersing its shorter leg in a vessel of water, applying the mouth to C, and exhausting the air, the pressure of the atmosphere on the fluid DE will force it to ascend in the tube: as soon as this has become filled with water, remove the end C from the mouth, and the water will continue to flow through the syphon until the vessel is emptied. The theory of its action is simple; let *sb* be the short and *sd* the long leg of the syphon filled with water. If the leg *sd* terminated at *n*, the pressure at *b* and *n* would be equal, and no fluid would escape, but *sd* being longer than *bs* by the distance *nd*, there must of necessity be greater pressure exerted at *d* than at *b*, and hence the water escapes at *d*; possessing the same velocity as if it had fallen freely from *n* to *d*. If *b* is immersed in a vessel of water, the pressure of the atmosphere will cause the latter to rise in the tube, and thus by this instrument the vessel is readily emptied. The length of the legs of the syphon is calculated from the top *s* to a line corresponding to the level of the fluid in which the short leg is immersed. If the long leg of the syphon be immersed in the water instead of the short one, and it be filled with the fluid by exhausting it with the mouth, the upward pressure of the air against the water in the shorter leg will be sufficient to drive it back into the vessel: consequently no syphon will act, unless the leg outside the vessel be sufficiently long to reach below a line corresponding to the level of the fluid.

Fig. 135.

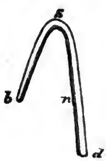
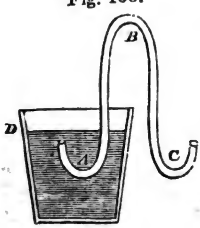


Fig. 136.



214. A tube, ABC, with its extremities curved upwards, is a useful modification of the syphon; its action is readily understood. Being filled with water, and one of its legs immersed in the vessel D, the column of fluid above A will press upon the water in the extremity of the tube, and no corresponding pressure being applied to the fluid in C, it overflows and escapes from the orifice, forming a little jet d'eau. This instrument is termed the *Wirtemberg syphon.*

The well-known scientific toy, called Tantalus's cup, consists of a glass vessel (fig. 137), in which the bent tube ABC is concealed. The long leg A passes out through the stem of the cup; on pouring water into this glass, it will hold it like any other vessel, until the horizontal branch B becomes filled, and then the water will escape through this syphon, until it falls below the orifice of the leg C. The mouth of a little image is often fixed at B, to represent the fabled Tantalus; and as soon as the fluid rises to his lips, it escapes through the syphon.

215. Another philosophic toy, (fig. 138,) illustrating some of the principles already laid down, is known under the name of Hiero's fountain, and consists of two vessels connected by the tubes AB, the tube B connecting the upper part of C with the upper part of D; whilst A passes air-tight through D, connecting the reservoir E with the bottom of the vessel C, a jet tube passes through the re-

Fig. 137.

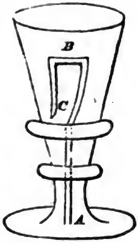
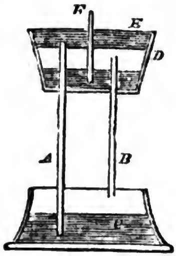


Fig. 138.



servoir E and extends to the lower part of D.—To use this apparatus, the vessel D and the reservoir E are nearly filled with water. The water placed in E falls down the tube A into C, forcing the air contained in the latter up B into D above the surface of the water in which it collects; more water falling down A, a larger quantity of air is forced through B into D; this eventually becomes so compressed as to act with great force on the water in D, and forces it to rise through the tube F, in the form of a jet d'eau. The mode in which this apparatus acts is, consequently, analogous to that of the compressed air-fountain (194 C), differing only in the manner in which the compression of the included air is effected.

Almost every instrument by which water is raised to any elevation, acts more or less directly through the medium of atmospheric pressure. A comparatively small number depend on ordinary mechanical means for producing their effect, as the screw of Archimedes, the Persian wheel, the chain-pump, &c., whilst the rope-pump depends upon capillary attraction for its action.

216. The comparatively incompressible character of water is made available as a powerful mechanical power, in Bramah's hydraulic press: this celebrated and valuable piece of apparatus consists essentially of a very strong water-tight box, the top consisting of a kind of piston, the upper end of which touches the substance to be submitted to pressure. The water-tight box, being filled with water by means of a small pump connected with it, the upper end of the piston presses forcibly against the substance exposed to its action. More water is then pumped into the already-filled vessel; and, in consequence of the law that no two bodies can occupy the same space at the same instant, something must yield; and as the piston is the most movable part of the apparatus, it is pressed with an enormous force against the substance submited to its action.

217. Currents of water are used as mechanical agents, in moving machinery, by means of the well-known contrivances called water-wheels; and currents of air are made equally available in turning the sails of the various forms of wind-mills. Indeed, in whatever light we regard the general and peculiar properties of both the elastic, or comparatively inelastic fluids, we cannot help being struck by the numerous ways in which they are so admirably fitted to supply the wants of man, and by which they are made available in adding to his various comforts, and ministering to his wants.

NOTE.

For further information on the contents of the last three chapters, the student should refer to the monographs in the Cyclopædias before referred to, and to the works of Dr. Gregory, Professor Young, Professor Playfair, Pouillet, Biot, Müller's Physics, Chap. III. to VI., and the three chapters of Section III., &c. The following are references to Newton's Principia and Euler's Letters:

Chap. VI. Newton, bk. ii. sect. 5.
VII. Newton, bk. ii. prop. 22, 23; Euler, vol. i. let. 9, 15, and vol. ii. let. 22.
VIII. Newton, bk. ii. prop. 36, and sect. 9.

CHAPTER IX.

SOUND.

Sonorous vibrations, 218. *Diffusion of Sound*, 219—*checked unless a conducting medium be present*, 220. *Sounds vary with condensation of air*, 221. *Laws of intensity of sound*, 222. *Circumstances modifying*, 223. *Communication of sound*, 224—*Velocity of*, 226—*Calculation of distances by*, 227—*Conducting power of bodies for*, 228. *Acoustic shadow*, 229. *Sonorous interference*, 230. *Passage of sound through mixed media*, 231-2—*Reflection of*, 234. *Echo*, 235. *Reflection of sound by curved Surfaces*, 236. *Transverse vibrations*, 237. *Planes of vibration*, 238. *Musical notes*, 239. *Comparative view of vibrations producing*, 241. *M. Biot's observations on sonorous waves*, 242. *Discords and concords*, 243. *Notes*, 245. *Vibrations of fixed rods*, 246—*of columns of air*, 247. *Acoustic figures*, 248. *Musical sounds evolved by heated metals*, 250.

218. WHEN the air, or any other elastic body, is made to assume a vibratory motion, consisting of a series of oscillations or undulations (207), repeated with sufficient frequency, a *sound* is produced. During the existence of such motions, the molecular arrangement of the vibrating body becomes altered, but acquires its normal state on their cessation. Thus, if a copper ribbon, 9 feet long, 0·4 inch wide and ·04 thick be vibrated, its length will appear unaffected. Let a weight of 90 lbs. be fixed to its lower extremity, and still no change occurs, but if again made to vibrate, its molecular arrangement will become permanently affected, as shown by its length becoming increased 6 or 7 inches. When these vibrations take place in a uniform and regular manner, as when a harp-string is struck by the finger, a perfect sound or *tone* is produced; but if the vibrations take place irregularly, and are not isochronous, as in the explosion of a pistol, a *noise* alone ensues.

219. When isochronous (81) vibrations are excited with sufficient rapidity in an elastic body, not less than 16, or, according to some, 30, in a second of time, their effects become transmitted by the excitations of fresh and similar movements in surrounding bodies and the air, extending on every side like the gradually widening circular ripples surrounding the spot where a falling drop of rain disturbs the surface of a pool of water (173). These eventually impinge upon the membrane of the tympanum, or drum of the ear; which

then assumes a vibratory movement. From this membrane tremulous motions are excited in the fluid with which the labyrinth of the air is filled, through the medium of the included air, or by means of the delicate chain of bones connecting them, or both; and which, acting on the auditory nerve, produce the sensation of sound.

220. Providing no substance intervene between the vibrating body and the ear, no sound is heard. If a bell be placed under the receiver of an air-pump (192), and the apparatus be shaken, the sound excited by the clapper striking the sides of the bell is distinctly heard. Let the air be exhausted from beneath the receiver, and the bell again agitated, the clapper will be seen to strike its sides, but no sound will be audible; in consequence of no elastic medium existing of sufficient density to convey the sonorous vibrations to the sides of the receiver.

221. Travelers, on ascending lofty mountains, have noticed the extraordinary diminution of the intensity of sound, in consequence of the rarefied state of the atmosphere at considerable elevations above the level surface of the earth (180). Saussure found that, on the summit of Mont Blanc, the explosion of a pistol appeared no louder than that of a cracker, and conversely the intensity of sound increases, on increasing the density of the air surrounding the sonorous body; thus sounds, which are of ordinary pitch in the free air, acquire a painful degree of intensity if heard in a reservoir of condensed air, or in descending in a diving-bell, in which the air becomes condensed by the upward pressure of the water.

222. The intensity of sound, like that of attraction (21), diminishes in the inverse ratio of the squares of the distances of the sounding body. This law, however, applies with its full force only when opposing currents of air, or other obstacles, do not interfere; for the sound of a church-bell is inaudible, during a contrary wind, at the distance of a few yards, whilst the sound of the cannonading at Waterloo is said to have been heard at Dover; and the noise of a sea-fight between the English and Dutch, in 1672, was heard at Shrewsbury, a distance of 200 miles. In these cases the intensity of the sound was no doubt preserved through these distances, by the presence of aerial currents, moving in the directions in which the sounds were heard.

223. From the researches of Dr. Derham, the intensity of sound is modified —A. By the direction and velocity of the wind. B. By varieties in barometric pressure. C. By changes in the temperature of the air. D. By its hygrometric state. E. By the original direction of the sound. F. By the nature of the surface over which the sound passes.

Sound is heard with great distinctness over a considerable space, in a frosty air undisturbed by winds or aërial currents. Lieutenant Forster, in the third Polar Expedition of Captain Parry, held a conversation with a man across the harbor of Port Bowen, a distance of one mile and a quarter.

224. When the air is in a state of sonorous vibration, it excites similar movements in bodies with which it is in contact, if they be properly situated. This may be shown by tuning two harp-strings in unison; on causing one to sound, the air surrounding it assumes a vibratory movement, and, this being propagated to the second string, causes it to vibrate, and emit a sound or tone. Instances have occurred of persons who, by modulating their voices, have excited vibration in glasses, so powerful as to overcome the aggregate attraction that held the particles together; and consequently to break them in pieces.

225. Waves on the surface of water, unless they differ very greatly in size, are capable of passing over each other without being destroyed. And in a similar manner, in the case of the waves of sound, or sonorous vibrations, excited by a crowded orchestra, an attentive ear can readily distinguish the sound of any particular instrument.

226. Sounds, in traversing given distances, are propagated with equal rapidity, passing through spaces proportional to the times. Sir John Herschel has shown that sounds of every intensity travel at the temperature of 62° Fahr. at the rate of 1125 feet per second, equal to 9,000 feet in 8 seconds, 12¾ miles per minute, or 765 miles in an hour. At a freezing temperature and in perfectly dry air, the rapidity of the propagation of sound is increased; as it traverses 1090 feet or rather more than 363 yards in a second. Any alteration of temperature of the air equal to one degree of Fahrenheit's thermometer, causes a corresponding alteration of 1·14 feet in the velocity of sound; this velocity increasing with the diminution of temperature.

227. By knowing the velocity of sound per second, we can gain, in many instances, a close approximation to a knowledge of the distance of a vibrating body. As light travels with an enormous velocity as compared to sound, we can, by observing the number of seconds elapsing between the appearance of a flash of light and the instant when the sound produced simultaneously with such flash is heard, and multiplying this number by 1125, ascertain the distance in feet from the source of the explosion. The following are some examples of this kind.

(A.) A flash of lightning is seen 12 seconds before the thunder is heard; what is the distance of the cloud where the explosion occurred?

$$8'' : 9000 \text{ ft.} :: 12'' : 13{,}500 \text{ ft.} = 4500 \text{ yards.}$$

(B.) The flash of a cannon fired from a ship is seen 33 seconds before the report is heard; what is the distance of the vessel?

$$8'' : 9000 \text{ ft.} :: 33'' : 37{,}125 \text{ ft.} = 12{,}375 \text{ yards.}$$

228. Sound is not transmitted with equal facility through all media: thus, various gaseous mixtures assume sonorous vibrations with extreme difficulty. The sound of a bell under the receiver of hydrogen gas is, according to the experiments of Dr. Priestly and Sir John Leslie, scarcely louder than when placed under an exhausted receiver (220). When hydrogen is respired, the voice of the person undergoes a curious change, being rendered extremely feeble, and raised in pitch, as we should expect it to be, from the lungs and larynx being filled with a rarefied medium.

Sound travels through different bodies with very different degrees of velocity. Thus, calling its velocity in air = 1, it travels in—

VELOCITY.

Distilled water	4·5	according to Laplace.
Sea water	4·7	Do.
Tin	7 5	Chladni.
Silver	9·0	Do.
Cast iron	10	Bibot.
Brass	10·5	Laplace.
Copper	12	Chladni.
Hammered iron	17	Do.
Wood	11 to 17	Do.

229. Sounds generated in air are indistinctly heard by a person immersed in water; but if excited in that fluid, they are conveyed to a considerable distance with facility. M. Colladon heard the sound of a bell struck under water across the whole breadth of the lake of Geneva, a distance of nine miles; this sound appeared to pass through the water with a velocity of 4708 feet per second.

Sounds excited in air are distinctly audible to persons cut off from recti-

near communication with the body by a projecting wall, although with some diminution of intensity. In water, however, M. Colladon found that the presence of a wall or rock projecting between the ear and sounding body, nearly rendered the sound inaudible, as though a sort of "*acoustic shadow*" had been produced by the wall.

230. Two sets of sonorous vibrations of equal intensity, encountering each other in opposite phases of vibration, will interfere, and become mutually checked; and thus silence will be produced by the conflict of two sounds. To understand this interference of sonorous vibrations, let us suppose that two strings are tuned so nearly in unison that one performs 100 and the other 101 vibrations in a second of time. During the first few vibrations, the resulting sound will be double the intensity of that produced by a single string, because the aërial waves exerted by the strings nearly agree in the time of their production. This relation, however, will soon cease, and at the expiration of half a second, one end will be in the act of performing its fiftieth vibration and the other will be half a vibration in advance. The phase of elevation of one will thus coincide with the phase of depression of the other (176), and an instant of silence will occur. Let the lines *a b* represent the apparent path of two aërial vibrations or waves excited by the sounding strings at the end of half a second; *ac*, *cb*, will represent each the course of two undulations, which, for the sake of illustration, are here supposed to be progressive (79); *e* will represent each phase of elevation, and *d* each phase of depression of a wave of air, the two undulations will meet at *b*, in opposite phases, one being in the act of elevation and the other of depression, thus both being equal in intensity, they neutralize each other's effects (176), and silence results. This may be shown by vibrating a common tuning-fork or diapason, and holding it over the mouth of a cylindrical glass vessel, A; the air contained in which will assume sonorous vibrations, and a *tone* will be produced. Then hold a second glass cylinder in the direction shown by the figure B, at right angles to A, and immediately the musical tone previously heard will cease; withdraw B, the tone reappears; approach it, and it once more disappears, and so on. These curious phenomena arise from the interference of the sonorous vibrations excited in the air contained in the glass vessels.

Fig. 139.

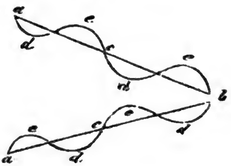
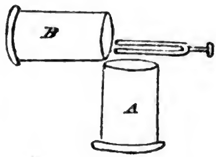


Fig. 140.



231. Again, when a tuning-fork vibrates, its branches alternately recede from and approach each other, as shown by the dotted lines in the figure, both communicating their movements to the air, and producing a musical sound. Let a fork whilst vibrating, be held upright about a foot from the ear, and slowly turned round. It will be found that when both branches are equi-distant from the ear, or when they coincide in direction, a distinct tone is heard, whilst in all intermediate positions scarcely any sound can be detected. This is explained by the fact, that when the branches coincide, or are equi-distant from the ear, the waves of sound combine their effects, whilst in all intermediate positions, as they reach the ear in different phases, they interfere and produce total or partial silence.

Fig. 141.

232. The passage of sound through heterogeneous media composed of substances of different degrees of elasticity, is effected with difficulty; for in passing from a less to a more elastic portion, sonorous waves of different intensities are excited; which, partly being reflected (234), and partly from mutual interference (230), become broken up, as it were, into myriads of secondary vibrations; and thus, the sound, which eventually reaches the ear, will be not only of less intensity, but of a different tone from the true one. If some portion of a mixed medium be capable of conducting sound better than others, some vibrations will reach the ear before the others, and a confused false sound will alone be heard. We have an example of these facts in a glass vessel filled with carbonic acid; this, when struck, instead of emitting the full tone proper to it, will merely produce an irregular flat sound: here the medium in which the vessel is immersed, the air, is of very different density and conducting power from that with which the glass vessel is filled, and accordingly vibrations of different densities are excited, which, probably, by their interference, deaden the proper tone of the glass vessel. Humboldt explains the fact of sounds being more readily audible at night than in the day, by the greater homogeneity of the atmosphere at that time. In the day-time its density being constantly changing by partial variations of temperature.

233. The comparative conducting power of different media for sound was well illustrated by an experiment of Biot's. This philosopher fixed a bell at the end of a long iron tube; on striking it, two consecutive sounds were heard by an observer at the opposite end, one conducted by the iron itself, the other by the air in its interior. The well-known double report of a fowling-piece, fired at a distance, probably arises from a similar cause, the sound of the explosion being conducted to the ear, unequally by the air, and the masses of vapor floating in it.

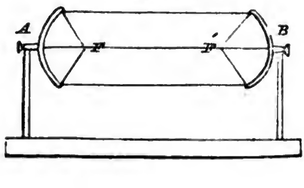
234. Sonorous vibrations, on impinging upon a plane surface, are reflected from it in such a manner, that the angles of incidence and reflection are equal, in the same manner as in the case of collision of an elastic body against a plane surface (62); the rapidity and intensity of the sound continuing the same after, as before reflection.

235. When a sound is reflected from a plane, and reaches the ear after a certain interval, an *echo* is produced; for this to be perfect, the observer must be at a certain distance from the reflecting plane; and the syllable will be repeated once or several times, according to the number of reflecting surfaces presented by the body against which the sound impinges. The reflecting plane must be at a greater distance to afford polysyllabic echoes. At Woodstock is one of this kind, repeating seventeen to twenty syllables.

When sound is reflected between parallel planes, at a proper distance from each other, multiplied echoes are produced, repeating syllables an almost indefinite number of times.

236. Sound is reflected by curved surfaces in the same manner as light and heat. Let A B be two mirrors composed of any hard polished substance, and in the focus of A at F, a low sound, as a whisper, be uttered.

Fig. 142.



The sonorous vibrations thus excited will, on reaching A, be reflected in the direction of a series of lines parallel to those drawn in the figure, to B, from the concave surface of which they will converge to a focus at F′, and be distinctly audible to an observer situated there. In a similar manner, any sound in an elliptic chamber, uttered in one of the foci of the ellipse, will be audible to an observer placed in the other focus, whilst persons placed midway will not be able to hear it (178).

If the substance against which the sound impinges be soft and yielding, it will be much diminished in intensity; thus, while voices are heard in a remarkably sonorous manner in lofty apartments with large polished walls, they almost cease to be audible in chambers hung with tapestry, from the sonorous vibrations becoming checked or absorbed, on impinging against this soft and yielding material.

237. When cords are made to vibrate in a transverse direction, as by drawing a bow across a violin-string, or by touching a harp-string with the fingers, the following phenomena are observed.

(A.) Cords of the same diameter, and equally stretched, have the number of vibrations in a given time, in their inverse ratio of the lengths. Thus, a cord, performing thirty-two vibrations in a second, will, if shortened to one-half, produce sixty-four, and if to one-third, ninety-six vibrations, in the same time.

(B.) Cords of the same length and degree of tension, have the number of their vibrations in the inverse ratio of their diameters; ex. gr., a cord of diameter three, will produce thirty-two vibrations in a given time, of diameter two, sixty-four vibrations, and of diameter one, ninety-six vibrations, in the same interval of time.

(C.) Cords of the same diameter and length have their number of vibrations in the direct ratio of the squares of the weights with which they are stretched: ex. gr., a harp-string stretched with the weight of one, will produce a certain number of vibrations; with a weight of two, will produce four times as many; and with one of three, nine times as many in the same space of time.

238. Sounds of the same pitch, may differ materially in their character, so far as sweetness of tone is concerned, quite independently of the number of vibrations producing them. Thus it is notorious that two players, on drawing a bow across the same string, will produce tones of very different character, although of the same note. It seems probable, from the researches of Dr. Young, that this is connected with the plane in which the string vibrates (85), and with the curve it describes. By reflecting a ray of light from the shining surface of a vibrating string, Dr. Young was enabled to observe some of these curves. The following are examples of some thus described by the centre of a vibrating string.

Fig. 143.

239. When a sound is produced by vibrations sufficiently regular to constitute a musical tone (218), each being produced by a certain and definite number of vibrations, it is termed a *note;* and to distinguish one from the other, a series of terms are applied to them. These, in this country, are taken from the alphabet, the first seven letters being used to designate particular notes.

On the continent, the seven syllables, *ut*, *re*, *mi*, *fa*, *sol*, *la*, *si*, are usually preferred. These *notes* constitute what is termed the *Diatonic* scale or *gamut*. A note is said to be sharper than another, when it is produced by a larger number, and to be graver or baser than another, when by a smaller number of vibrations in a given time. The gravest audible *musical* sound is produced by about sixteen, and the sharpest by about 2000 vibrations in a second. This, however, is subject to great latitude, for, as Dr. Wollaston long ago showed, many sounds at either extreme of the scale utterly inaudible to some persons, are distinctly perceived by others. The chirp of the cricket and cry of the grasshopper, are produced by such a rapid succession of vibrations, that to many persons they can scarcely be appreciated as musical sounds. A fine ear is able to recognize as a distinct sound, a peculiar hissing noise made by a body completing 24,000 distinct vibrations in a second. M. Savart has, by means of a series of very interesting experiments, shown the high probability of there scarcely being any definite limit to the audibility of sounds, providing they were sufficiently loud. By means of a rapidly rotatory cogged wheel, so arranged that each tooth should strike a piece of card, he found that 12,000 strokes on the card produced a sound perfectly audible as a musical sound of high pitch.

240. M. Biot* has calculated the lengths of sonorous waves produced by different numbers of vibrations in a given time. The results of his observations are shown in the following table.

	Vibrations in a *second of time.*	Length of *resulting wave* in feet. (French.)	
	1	1024 ft.	
	2	512	
	4	256	
Probable utmost range of sounds audible by the human ear.	32	32	These sounds are identical with those produced by an organ-pipe open at both ends, and of the same length as that of the sonorous wave, given in this column.
	64	16	
	128	8	
	256	4	
	512	2	
	1024	1	
	2048	6 in.	
	4096	3	
	8192	$1\frac{1}{2}$	

241. A collection of eight consecutive notes is termed an octave, and one octave is said to be higher or lower than another, when the notes it contains are produced by a greater or smaller number of vibrations in a given space of time.

A note of any octave is produced by a certain number of vibrations, which are twice as numerous as in the corresponding note of the next lower, and are half as numerous as in the corresponding note of the next higher octave.

* Précis de Physique, i. 357.

Names of Notes.		Comparative		Number of vibrations in a second.
Continental.	English.	length of string.	number of vibrations.	
ut	C	1	1	258
re	D	$\frac{8}{9}$	$\frac{9}{8}$	290
mi	E	$\frac{4}{5}$	$\frac{5}{4}$	322
fa	F	$\frac{3}{4}$	$\frac{4}{3}$	344
sol	G	$\frac{2}{3}$	$\frac{3}{2}$	387
la	A	$\frac{3}{5}$	$\frac{5}{3}$	430
si	B	$\frac{8}{15}$	$\frac{15}{8}$	483
ut	C	$\frac{1}{2}$	2	516

In the above table, the continental names of the notes, their English synonyms, the comparative lengths of the strings, and number of vibrations producing them, as well as the absolute number of vibrations in a second performed by the strings to produce a particular note, are at once seen. The figures in the last column must be considered as only approximations to the true numbers. The octave there taken as an example, is the fourth from the base of the piano.

242. There is some little difference of opinion, as to the actual number of waves per second, producing a particular note. In the following table, we have the number of waves required to produce the middle A of the pitch adopted at different orchestras, which in the above table is stated to be produced by 430 vibrations in a second.

Theatre of Berlin	437·32
Paris, French Opera	431·34
—— Comic Opera	427·61
—— Italian Opera	424·14

In piano fortes, which for private purposes are generally tuned below concert-pitch, the middle A is produced by 420 vibrations in a second.

243. The perception of a simple musical tone has been aptly compared by Euler,* to a series of dots equi-distant from each other, thus,

. . . .

If the intervals between these dots be greater or smaller, the tone produced will be lower or higher (203). It can scarcely be doubted that the perception of a single tone by the ear is analogous to the appreciation by vision of such a set of equi-distant dots; thus enabling us to represent to the eye, in a certain degree, what the ear perceives on hearing sound. If the distances between the dots be not equal, or if they be irregularly scattered, they would represent a confused noise, inconsistent with harmony. When two tones, each produced by the same number of vibrations, strike the ear simultaneously, they appear to blend, forming a *unison;* which may be represented by two lines of equidistant dots, thus, : : : : : : : : : :

244. When the difference between the number of vibrations producing any two notes is in a simple ratio, so that the ear readily discovers the relation

* Letters to a German Princess, vol. i. let. 4.

existing between them, a *concord* is produced. But if from the absence of this simple ratio, this relation cannot be detected, a *discord* is said to result. The following are some of the most important concords.

(A.) The octave, represented by 2, because the sharper note is generated by twice the number of vibrations that the graver one is, corresponding to the interval of the two C's or *uts:* this concord is termed an octave, because in the musical vibration of notes the vibration of C and C² are in proportion


C D E F G A B C²

alluded to (1 : 2) and C² is the eighth note from C.

(B.) The fifth, $\frac{3}{2}$, the sharp note being produced by three vibrations whilst the base is produced by two in the same time, corresponding to the interval of C to G, or *ut* and *sol:* this concord is termed a fifth, because the vibration of G and C are as 2 : 3, and the former note is the fifth from the latter. A similar explanation applies to the numerical names of the other concords.

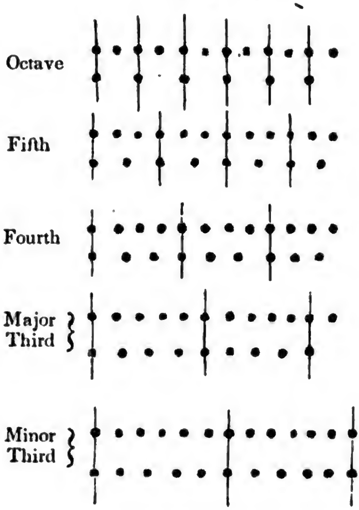
(C.) The fourth, or $\frac{4}{3}$, the sharp sound produced by four and the grave by three vibrations in a given time: thus corresponds to the interval of C to F, or *ut* to *fa*.

(D.) The major third, or $\frac{5}{4}$, corresponding to the interval C to E, or *ut* to *mi*.

(E.) The minor third, or $\frac{6}{5}$, is the interval E to G, or *mi* to *sol*.

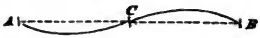
These concords are represented in the following diagrams; the upper line in each representing the sharp, and the lower the grave notes. Those vibrations which occur simultaneously, and therefore increase each other's powers, are connected by vertical lines.

Fig. 144.



245. If, when a string is vibrating, it be suddenly checked, by touching it in the centre, its two halves will vibrate twice as rapidly as the entire string, each producing the same note of the next higher octave. This sometimes occurs spontaneously, producing a series of *harmonic sounds;* it is readily produced in the strings of the harp and violoncello. When this phenomenon occurs, the point midway between the two ends of the string is at rest, whilst the rest is rapidly vibrating; any number of these points may exist in the same string; they are termed *nodi* (83). At these points the string never leaves the axis, for let the dotted line AB represent the direction of a stretched string, and, after it has been made to vibrate, it be touched with the finger at C, the two halves CB, CA, will begin to vibrate twice as rapidly as the entire string AB did, but in contrary directions, each end pulling equally from C will cause this point, or *node*, to remain at rest and in the direction of the long axis of the string.

Fig. 145.



246. When rods of metal, fixed at one end (97), are made to vibrate, they produce sonorous vibrations varying in number in the inverse ratio of the squares of their lengths, and in the direct ratio of their diameters. These rods, like strings, may vibrate entire, or divided into nodi.

247. When sonorous vibrations are excited by blowing into tubes, the sharpest notes are, *cæteris paribus*, excited by the shortest tubes. Sounds thus excited, are produced by the alternate condensations and expansions of the different layers contained in the column of air in the tube. The following are some of the more important facts connected with the relation between the sound evolved, and the length, and open or closed extremities of the tubes employed.

(A.) In cylindric tubes, *closed at one end*, the vibrations are in the inverse ratio of the length of the tube.

(B.) In a cylindric tube, *open at both ends*, the sound is the same as that produced by a cylindric tube closed at one end, and one half its length.

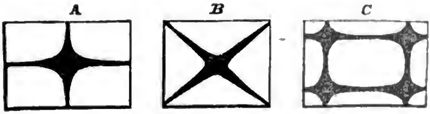
(C.) In a cylindric tube, *closed at both ends*, the sound is the same as in a tube closed at one end, and of one half its length.

(D.) Nodi, or points at rest, in the included column of air, are observed in the case of vibrations of this kind as in vibrating cords (245), or rods.

248. Vibrations are readily excited in elastic plates by friction or by striking them, and sounds are evolved; the plates dividing themselves into vibrating portions, separated by nodi or points of rest, arranged in lines. The position of these lines of rest is beautifully shown by scattering sand on the plates, and vibrating them; the sand will assume a curious rapid movement, and be thrown off the vibrating portions, upon the nodi or lines of rest. If a square plate of glass be grasped in the centre by a small hand-vice, sand scattered over its surface, and the bow of a violin drawn rapidly across it close to one of its angles, the sand will be thrown into the position shown in A. If the bow be applied to the middle of one of the

Fig. 146.

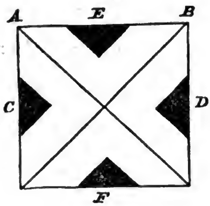
Fig. 147. Fig. 148. Fig. 149.



sides, the sand will be arranged as in B. If the plate be held near one of its angles, and the bow applied as before, the sand will be arranged as in C.

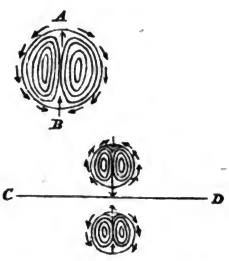
From a series of highly interesting experiments* on this subject, by Dr. Faraday, it appears evident that the scattering of sand on the nodal lines does not arise so much from its being, as it were, jerked off from the vibrating portions, as from the vibrations exciting currents of air over the agitated portions, which, entangling the powder scattered on the plate, carries it to the lines of rest, or *nodal lines*. If the powder be a very light one, as *lycopodium* instead of sand, this will be caught up by the aërial currents, and will collect chiefly on the most agitated portions of the plate instead of on the quiescent portions, and appear animated with a curious vortex-like motion. If the plate be vibrated in very rarafied air, the lycopodium will be collected on the nodal lines, like the sand when vibrated in ordinary states of atmospheric pressure; and if covered with sand, and made to vibrate in water, the sand will be collected chiefly on the most agitated portion of the plate. Thus, the lines AD represent the position of the sand when the plate is vibrated in air, and of the lycopodium when in vacuo; and the triangles ECDF, the parts or *inter-nodal spaces* where the sand is collected when the plate is vibrated in water, and the lycopodium when in air.

Fig. 150.



249. These acoustic figures may be well exhibited by stretching a piece of bladder over the mouth of a funnel, and passing a horse hair, retained by a knot, through its centre; on drawing the hair through the fingers, previously rubbed over the resin, the membrane will be made to vibrate, and if the sand be scattered on its surface, its symmetric arrangement may be observed. A very delicate mode of detecting acoustic vibration has been described by Strehlke:† he scatters some lycopodium on water, so as to cover its surface with the thinnest possible layer, which is best effected by agitating the fluid in a box, the inside of which has been rubbed over with the powder. On placing a drop of this on a vibrating body, the particles of lycopodium begin to revolve in the water, dividing into two or more currents, if the sonorous vibrations be intense, as shown at AB. If a drop be placed on each side of a nodal line, or line of rest (245), CD, these intestine motions occur, but in opposite directions.

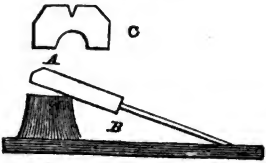
Fig. 151.



250. The evolution of musical sounds during the cooling of heated metals, observed by Mr. Trevelyan and others, is extremely curious. These phenomena are best observed by using the *thermophone*. This consists of a bar of copper five inches long and about half an inch thick, grooved in such a manner that its transverse section is like that of the marginal figure C. A piece of thick iron wire, about eight inches long, is fixed in one end for a handle. On heating the copper bar, and resting its convex portion on the edge of a

* Phil. Trans., 1831.
† Poggendorff, Annalen 40, p. 146.

Fig. 152.



block of lead, as at B, it will begin to vibrate strongly, and soon afterwards evolve musical sounds, usually beginning like the drone of the bagpipes, and rising to a loud plaintive swell, like that of the Æolian harp, and then falling in the most fitful manner. These wild and irregular sounds continue until the temperature of the block of lead and copper-bar are nearly equalized. They are evolved with the greatest shrillness when a small channel is filed out in the back of the bar, as shown in A, or a similar channel excavated in the surface of the leaden block on which it rests. It is necessary that the surfaces of the metals employed should be quite clean; and that their powers of conducting heat should be as different as possible; hence, copper and lead succeed the best, as the conducting power of the former for caloric, according to Despretz, is 398, and of the latter 179·6.

NOTE.

To no work on the subject of acoustics can the student refer with so much advantage as to Sir John Herschel's Monograph on Sound, in the Cyclopædia Metropolitana: here he will find all that is valuable on this subject. The reader will also find much that is of importance in the 4th section of Müller's Physics. The following are the references to Newton and Euler:

Newton, bk. ii. sect. 8.
Euler, vol. i. letter 3 to 8.

SECTION II.

PHYSICS OF IMPONDERABLE MATTER.

Magnetism, Chapter X. Ordinary Electricity, Chapter XI.—XIII. Atmospheric Electricity, Chapter XIV. Voltaic Electricity, Chapter XV. Electrolysis, or Electro-chemical Decomposition, XVI. Electro-dynamics, Chapter XVII. Electro-dynamic Induction, Chapter XVIII. Thermo-electricity, Chapter XIX. Physiological Electricity, Chapter XX. Luminous Undulations of Imponderable Matter, or Light—Unpolarized Light, Chapter XXI.—XXIII. Polarized Light, Chapter XXIV.—XXVI. Optical Instruments, Chapter XXVII. Calorific Undulations of Imponderable Matter, or Heat, Chapter XXVIII.—XXIX. Photography, Chapter XXX.

CHAPTER X.

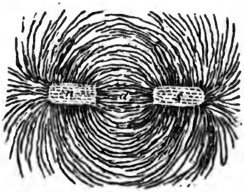
MAGNETISM.

251. The property of attracting pieces of iron, possessed by certain ferruginous ores, has been long known; and the ores themselves have been termed *magnets*, from Magnesia, a town of Lydia, near which they were stated by the ancients to abound. Pliny states that these ores were in his time termed *ferrum vivum*, or quick-iron. In England the term load-stone has long been applied to the native magnetic oxide of iron. All the phenomena possessed by such magnets, including their action on iron, cobalt, and nickel, and other metals which appear to obey their attractive influence, have been collected, and the important science of *magnetism* founded upon them.

Not only do ores of iron possess magnetic properties, but masses of that metal which have been placed in contact with them, or have been submitted to the effects of certain mechanical actions, generally present the phenomena of magnetism. The magnetic ores constituting what are termed *natural;* and the latter, *artificial*, magnets. In examining the phenomena they present, it matters not which we use; magnetic bars of iron, however, being generally preferred on account of their convenient form.

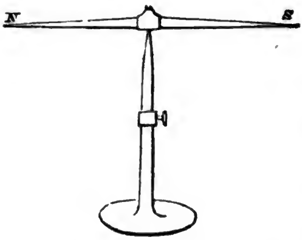
252. If a magnet be dipped in iron filings, it will attract them, causing them to adhere to its surface, but unequally in different parts; being collected in abundance at the ends, and nearly absent from the intermediate portions. This is best seen by placing a sheet of paste-board over the two poles of a horse-shoe magnet, scattering iron filings on its surface, and then tapping the paste-board lightly with a stick; the filings will arrange themselves in lines diverging from the poles of the magnet in curves, the centre *a* being nearly free from them: whilst the outline of both ends, *ns*, of the bar will be well defined by the iron filings, as shown in the magnetic figure. The extremities of the magnet, in which the magnetic action appears thus to be concentrated, are termed *poles*. The greatest intensity of action is not found to be exactly at the very ends of the magnet, but at a little distance from them, representing centres, from which the magnetic force appears to radiate. The curves formed by the iron-filings may be conveniently regarded as pointing out the existence of *magnetic lines of force*, and the space between the two poles as equivalent to a *magnetic field* or space where the two forces mutually react. The influence of the lines of

Fig. 153.



force traversing the magnetic field on certain bodies will presently fall under our notice.

Fig. 154.

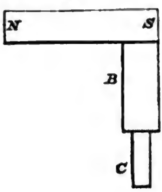


253. Let a magnetic bar be suspende4 by a thread tied round its centre, or by being fixed on a pivot as NS, so as to be free to move round avertical axis; and it will be found to assume, after a few oscillations, a constant position. If it be moved from this position, the bar will return to it as soon as the coercing force is removed. One of the poles (214) of the bar will be found to point constantly towards the north, and the other towards the south. The former N is, in common language, called the north, and the latter S the south pole of the magnetic bar (220, 223).

254. Approach towards the *north* pole of a magnetic needle placed on a pivot (215), the *south* pole of a second magnet held in the hand; immediately the former will move towards the latter, being attracted by it. If, then, the *north* pole of the magnet presented to the needle, be substituted for the *south*, the *north* pole of the movable magnet will fly round to attain the greatest distance possible from it, repulsion having taken place. Hence we learn that *poles of the same name repel, and those of different names attract each other.* That the attraction, or repulsion is mutual, may be proved by using two magnets on pivots instead of but one.

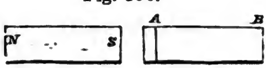
255. When a piece of iron is attracted by a magnet, it assumes magnetic properties. Present a piece of soft iron, B, towards the south pole (253) of a magnetic bar NS; it instantly becomes attracted. And if a second bar C, be presented to B, it will attract it almost as strongly as it is *itself* attracted by the magnetic bar; proving that B assumes magnetic properties under the influence of the bar NS. Gradually slide NS off B, and instantly the magnetic properties of the latter will vanish, and the bar C will fall from it. The influence exerted by NS on B, is termed *induction*, because it *induces* magnetic properties in the bar; retaining them in it, whilst they remain in approximation. If the end of B be dipped in iron filings whilst in contact with NS, they will adhere to it, and arrange themselves in curved lines. And in the experiment before mentioned (252), in which iron filings became arranged in curved lines, under the influence of a magnetic bar placed beneath them, the filings became magnetic by *induction*, each single one acting on its neighbor, like a little magnet on a pivot (253), attracting or repelling it according to circumstances.

Fig. 155.



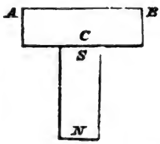
256. Whenever the pole of a magnet induces magnetism in a bar of iron, the end of the latter nearest either pole will acquire properties of the *opposite* kind to it. Thus, if the iron bar A B be brought near NS, it will become

Fig. 156.



magnetic by induction (256), the end A becoming the north, and B the south pole, providing the end S of the magnet were a *south*, and N a *north* pole. If the magnet SN be brought in contact with the middle of a bar of iron A B, the centre C will become a north pole, and the ends A B both south poles. And if the pole of a magnet be placed in the centre of a circular piece of sheet iron, the whole circumference will assume magnetic properties of the same kind as that of the pole of the magnet, whilst the centre with which it is in contact will assume an opposite polarity.

Fig. 157.



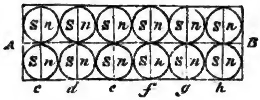
257. If a magnetic bar, NS, be broken in half in the centre, the half S will not be found to possess all southern, and N all northern polarity, as might perhaps be expected, but both portions will become perfect magnets, each of the fractured ends exhibiting a polar state, as perfect as the entire magnet. The fractured end s′, becoming a south, and n′ a north pole; although at this middle point where s′ and n′ join, no magnetism could, before breaking it, be detected.

Fig. 158.

258. From these and similar experiments, a tolerably satisfactory theory of magnetism has been framed, which, if not correct, is certainly very convenient, as affording a key to all the ordinary magnetic phenomena, and may be admitted as at least a conventional hypothesis. According to this theory, two distinct magnetic fluids exist, one consisting of *austral*, the other of *boreal* magnetism, and under the influence of either, in a *free* state, the bar of iron or other metal will point to the north or south poles of the earth according to circumstances. In ordinary iron, these fluids exist in a *combined* state, and therefore are perfectly latent, the metal appearing to be destitute of magnetism. These fluids exist in a certain proportion united to each molecule, or atom of the metal, and from which they *can never be disunited;* the only change which they are capable of undergoing being their decomposition into the separate elements, one of which in a permanent magnet, is always collected on one, and the other on the opposite side of each particle or molecule of metal.

This theory explains the curious circumstances of a magnet possessing no attractive influence in its centre, and of its magnetism being apparently concentrated in the poles; for if AB represent a bar magnet, consisting of two

Fig. 159.



rows of spherical molecules, the *austral* fluid will all be collected on the sides of the atoms nearest B, as shown by the letter *n*; and the *boreal* fluid on those nearest A, or on the sides where the letter *s* is placed. Then, the effects of the *austral* fluid collected on one side of the molecule *c*, for example, will be completely counteracted by the *boreal* fluid on the opposite side of *d*, the *austral* of this by the *boreal* of *e*, and so on, until we come to the last molecule *h*, whose *austral* side, having no other atoms to oppose its action, will exert the ordinary attractive and repulsive effects of free magnetism. In the same

manner the *boreal* side of *c*, will exhibit the phenomena of free magnetism; the particles in the second row will also be similarly arranged, and exhibit similar phenomena. Thus we see that the central portions of a bar magnet *cannot* exhibit evidence of free magnetism, because the magnetic fluid in one particle is held virtually neutralized, or disguised, by that next to it, and so on.

259. An extension of this mode of reasoning will show why a steel ring may be converted into a magnet, by passing it over the pole of a permanent magnet, without its exerting any attractive influence on iron, or exhibiting any other phenomenon characteristic of free magnetism; for here every portion of the ring being *continuous*, the separated fluid on the side of every atom is held *disguised* by the free fluid of the opposite kind, on the opposed side of the next atom of steel in the series. On breaking such a ring in half, the terminations of the fractured portions will be found to present energetic magnetic polarity, from the portions which disguised their polar state being removed. And thus every fragment of a fractured bar is a perfect magnet, a fact so interesting and extraordinary that the Abbe Häuy has wittily termed magnets *les polypes du regne mineral.* A German philosopher, Eschenmaier, has proposed the following formula as exhibiting an hypothetical view of the arrangement of magnetism in a magnetic bar; it certainly points out the absence of polar properties in the centre, and their gradual increase as we approach the extremities of the bar:

$$\mathrm{M}^{n} \text{———} \mathrm{M}^{3}\ \mathrm{M}^{2}\ \mathrm{M}^{1}\ \mathrm{M}^{0}\ \mathrm{M}^{-1}\ \mathrm{M}^{-2}\ \mathrm{M}^{-3} \text{———} \mathrm{M}^{-n}$$

the letter M, with the positive exponents 1, 2, 3, &c., representing one (as the *austral*) fluid, and with the negative exponents —1,—2,—3, the other, or *boreal* fluid.

260. The phenomenon of induction admits of a similar explanation; for if the *austral* pole, (or that which, if freely suspended, would *point to the north*,) of a large magnet be placed at A, in the last figure (258), and a soft iron bar *c*, *d*, *e*, *f*, *g*, *h* be placed nearly in contact with it, the combined magnetism will be decomposed; the *boreal* fluid of each molecule will be attracted to the side of the atoms of iron nearest A, its *austral* fluid repelled to the opposite sides, and the bar of iron will become a magnet. If the coercing influence of the magnet A be then removed, the separated magnetic fluids recombine, and the bar of iron is left free from magnetic properties; but if the bar be of hard iron or steel, the inductive action (255) of the magnet A, although far less powerful, is considerably more permanent, for the magnetic fluids remain separated after the removal of the magnet which induced their separation, or decomposition. Indeed, it would appear that the closer texture and greater density of hard iron or steel, are physical conditions which oppose themselves mechanically to the free and ready movements of the imponderable fluids imprisoned in the interspaces existing between their molecules.

261. A magnetic bar properly balanced upon a pivot (253) is generally termed a *needle*, and constitutes the active agent in the well-known mariner's compass; guiding the sailor when all other indications of his course fail him. This valuable instrument was used in Europe in 1180, according to a satirical poem of Guy of Provence, entitled "La Bible," in which it was minutely described. It is tolerably certain that it was known to the Chinese, in a rude and imperfect form, under the name of *Tchi nan*, or chariot of the south, about 2600 years before the Christian era. Marco Paolo was the first European navigator who applied the compass needle to the practical and important purposes for which it is now constantly used, in his return to Europe from the East Indies in 1260. This important property of a magnetic needle pointing towards the north and south poles of the earth, has been variously accounted

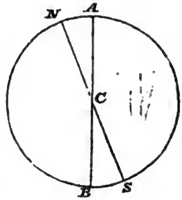
for; thus Cardan has supposed that a star lodged in the constellation of Ursa Major attracts the needle, whilst others with more probability have supposed the earth to be, or to contain an enormous magnet, whose poles nearly correspond to the geographical poles of the globe.

262. It seems, however, that, admitting the existence of but *one* magnetic pole in either hemisphere, it is difficult to explain the phenomena noticed by different observers. In the northern hemisphere, two poles or centres of attraction have been distinctly made out, one in Siberia at 102° E. long.: and to the north of 60° lat.: the other, and apparently far the most important, is situated about 96° 40′ W. long.: and 73° 14′ N. lat.: these two poles are about 200° apart, measured across Greenland and Norway. The two southern poles are supposed to be located, one near Cape Horn, and the other to the south of Australia. If this be admitted, we must suppose that a large collection of free *boreal* fluid is laid up in the northern, and of *austral* in the southern hemisphere, each having their greatest intensities respectively at the points just mentioned. And in this case, that pole of the magnetic needle which points to the north, contains free southern, or *austral* magnetism; because poles of the same name repel each other (254), and accordingly that pole of the needle which points towards the north has been termed *austral*, and that towards the southern *boreal*. Prof. Hansteen supports this notion of the existence of two magnetic poles in each hemisphere; he however places them rather differently. On the other hand a high authority, Prof. Gauss, from very recent researches, is induced to contend for the existence of a single pole in each hemisphere. Dr. Faraday is, however, of opinion that the hypothesis of the existence of magnetic poles at the geographical poles is unsatisfactory, and that the phenomena of the dipping needle lead to one of two things; either that the magnetism of the earth is simply the result of the induction of electric currents (491), or if a terrestrial magnet really exists, its poles must be close together near the earth's centre.

263. Some philosophers have, with the celebrated Berzelius, preferred the terms *negative* and *positive* magnetic fluids, to austral and boreal. It signifies but little which are adopted, provided their conventional meanings are well understood, and as the terms *austral* and *boreal* are almost universally used, I have preferred them. It is only necessary to recollect, in reference to a magnetic bar, that *boreal*, *southern*, and *positive*, all refer to that pole which would point towards the south; and *austral*, *northern*, and *negative*, all refer to that which would, if freely suspended, point towards the north.

264. The magnetic needle does not point exactly north and south, a circumstance generally supposed to have been first observed by Columbus in his earliest voyage of discovery in 1492; and consequently the magnetic meridian, or plane bisecting the earth in the direction of the needle, does not coincide with the geographic meridian. The magnetic meridian is not constant, sometimes being on the east, and sometimes on the west of the geographic meridian; this difference is termed the magnetic *declination*, or more commonly, magnetic *variation*. Thus, if AB represent the geographic meridian, NS will represent the direction assumed by a compass needle, or magnetic meridian, and the angle NCA is termed the angle of declination, or variation. In certain portions of the earth the magnetic and geographic meridians appear to coincide, as in some parts of North America, the north-eastern point of South America, western part of Australia, &c. These places are connected by imaginary

Fig. 160.



irregular curved lines, termed the *lines of no variation.* This line appears to move progressively over the surface of the globe; it passed over London in 1660, in which year the needle there pointed exactly to the north, and in 1663 it passed over Paris. In its westward course it has lately traversed America. These have been lately termed by Prof. August, *agonic* lines, and two of them are supposed to exist, one in the western hemisphere termed the American *agone*, and another in the eastern, or Asiatic *agone.* They both intersect the geographic meridians at different angles. Prof. Gauss is induced to believe that there exists a greater and lesser agone; the greater embracing the globe like a meridian, passing through the magnetic pole and dividing the earth into an eastern and western magnetic hemisphere. Of these the former will embrace Australia, Arabia, Persia, and Russia; the latter including the eastern parts of North and South America. Gauss's lesser agone forms an oval, and runs through Eastern Siberia and China. The mean declination in Europe is about 17°, increasing towards the west and decreasing towards the left.

Declination or Variation of the Needle at

LONDON.			PARIS.		
Year.	Variation.	Direction.	Year.	Variation.	Direction.
1580	11·16	E.	1580	11·30	
1634	4·6	E.	1618	8·0	
1660	0·0	—	1663	0.0	—
1670	2·30	W.	1678	1·30	W.
1690	6·0	W.	1700	8 10	W.
1720	14·17	W.	1767	19·16	W.
1740	17·0	W.	1780	19·55	W.
1750	17·48	W.	1785	22·0	W.
1770	21·9	W.	1805	22·5	W.
1780	23·17	W.	1813	22·28	W.
1790	23·39	W.	1817	22·19	W.
1800	24·3	W.	1822	22·11	W.
1810	24·11	W.	1825	22·12	W.
1818	24·30	W.	1832	22·3	W.
			1835	22·4	W.

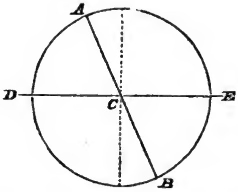
265. Prof. Renwick found the variation of the magnetic needle to amount to 5° 28′ W. at New York in 1837. At London the needle at present points about 24° west of the true north pole, the maximum variation having been attained in 1818, when it amounted to 24° 30′. The preceding table presents a view of the variations of the magnetic needle in London and Paris during several years.

The greatest variations ever observed, were by the Chev. de Langle, between Greenland and Labrador, amounting to 45° W.; and by Captain Cook, in 60° S. lat. and 92° 35′ long., when the variation amounted to 43° 6′, east of the geopraphic meridian.

266. The magnetic needle, if suspended on an axis at its centre of gravity, does not remain horizontal; its *austral* end in our hemisphere dipping considerably, and appearing the heaviest; and in the southern hemisphere the opposite pole inclines: this is termed the dip or inclination of the needle, and a needle thus suspended is termed a *dipping-needle.* At the equator, this dip *nearly* disappears, as both the poles are equidistant from the geographic poles

of the earth, although it does not disappear entirely at the geographic equator, as this differs from the magnetic equator or the situation where the needle is horizontal, in a similar manner as the meridians differ (264). Let AB be a

Fig. 161.



needle balanced on its horizontal axis C; in England, then, instead of remaining horizontally, as DE, it dips or inclines towards the north, its austral pole forming an angle CBE of nearly 70° with the horizontal line DE.

267. The magnetic equator is tolerably regular for a part only of its course, and may be represented by a part of a large circle inclined at an angle of 12° to 13° to the geographic equator, which it intersects in at least two or three points. In the southern hemisphere, however, especially between the Sandwich and Friendly Islands, this line presents numerous irregular and sinuous curves like the magnetic meridian. The magnetic equator is not circular, but is really an irregular double curve to which the term of *aclinic* line has been applied; it, like the *agonic* lines (265), appears to be undergoing progressive motion, which, as far as observations have been made, is in a direction from east to west. The *aclinic* line intersects the equator at several points; one is at the present time near the island of St. Thomas in 3° E. long., another in the Pacific at 142° E. long. A line connecting places where the inclinations corresponded is called *iso clinic.* The inclination or dip of the needle undergoes periodic variations, but by no means to so great an extent as the declination (264).

Inclination of the Needle at			
LONDON.		PARIS.	
Year.	Angle of Inclination.	Year.	Angle of Inclination.
1680 . .	. 73°·30′	1798 . .	. 69°·51
1723 . .	. 74 ·42	1810 . .	. 68 ·50
1773 . .	. 72 ·19	1818 . .	. 68 ·35
1786 . .	. 72 ·8	1824 . .	. 68 · 7
1790 . .	. 71 ·53	1825 . .	. 68 · 0
1800 . .	. 70 ·35	1826 . .	. 68 · 0
1818 . .	. 70 ·34	1829 . .	. 67 ·41
1828 . .	. 69 ·47	1831 . .	. 67 ·40
1830 . .	. 69 ·38	1835 . .	. 67 ·24

The greatest *inclinations* of the needle ever observed, were by Captain Cook, who, in 60° 40′ S. lat. observed it to be 43° 45′; Captain Phipps, in 1773, in 79° 44′ N. lat. found it to be as great as 82° 9′, or nearly vertical;

and Sir James Ross, in 1831, in the vicinity of Hudson's Bay, in 70° 5′ 17″ N. long., found the dipping needle to be within one minute of being perfectly vertical.

268. The inclination of the magnetic needle was discovered by Robert Norman in the 16th century, who found it to amount to 72°. The diminution of the magnetic dip has been going on in London for the last half-century with great regularity, at the rate of about 3′ annually. Prof. Krafft of St. Petersburgh announced in 1809, a very simple law governing the intensity of the dip, at different parts of the earth's surface, which has been confirmed by the later researches of M. Biot, viz.: if we measure the latitude of any place from the magnetic equator, and calculate its tangent, it will be found exactly equal to half the tangent of the dip of the magnetic needle at the particular locality.

269. From the observations of M. Quetelet, it appears that the angles of inclination and declination seem in Europe to be undergoing a tolerably constant gradual diminution: these angles at Brussels were found by this philosopher to be of the following values:

Month.	Year.	Inclination.	Declination.
October	1827	68°·56′·5″	22°·28′·8″
March	1830	68 ·52 ·6	22 ·25 ·3
March	1832	68 ·49 ·1	22 ·19 ·0
March	1833	68 ·42 ·8	22 ·13 ·4
April	1834	68 ·38 ·4	22 ·15 ·2
March	1835	68 ·35 ·0	22 · 6 ·7
March	1836	68 ·32 ·2	22 · 7 ·6
March	1837	68 ·28 ·8	22 · 4 ·3
March	1838	68 ·26 ·1	22 · 3 ·7
March	1839	68 ·22 ·4	21 ·53 ·6

270. In addition to these, the compass-needle, like the barometer, undergoes daily and even hourly variations. The diurnal variations of the needle are such, that its *austral* pole moves towards the west from sunrise to about an hour after noon, when it retrogrades towards the east, until eight o'clock in the evening, after which, it remains nearly stationary, until sunrise. The amplitude of these variations differs considerably in different parts of the earth, and even in different months of the year; in London it attains, in June and July, 19′·6″, and in December 7′·6″. In Paris, its maximum is as in London in June and July, and varies from 13′ to 16′, falling in December to 8′ or 10′. In the northern parts of Europe and America the diurnal variations are more considerable, but less regular; and under the magnetic equator (267) they vanish entirely; and on the south of the equator they reappear in an inverted order.

Recent observations have indicated the frequent existence of *magnetic storms*, in which the needle becomes acted upon in a very remarkable manner. For a most elaborate and interesting account of these extraordinary results I beg to refer to a paper read by Dr. Brooke before the Royal Society in 1847. This gentleman contrived an apparatus with the most consummate ingenuity and skill, by which all the variations of the magnet were self-indicated by means of a pencil of light reflected by a mirror fixed to the suspended magnetic bar, impinging upon a strip of sensitive paper (871) fixed to a glass cylinder revolving by clockwork on its axis once in 12 hours. It is impossible in this

work to do justice to these important observations, but I would refer my reader to Dr. Brooke's paper, published in the Philosophical Transactions, not only for its great value, but for its being a model of patient research guided by remarkable talent.

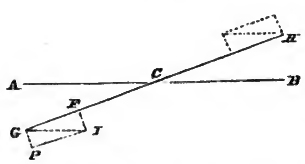
271. Besides these *regular* variations, there are others connected with certain meteoric and electric phenomena; the appearance of the aurora borealis, an eruption of a volcano, a flash of lightning, all exert perturbing effects upon the magnetic needle. The latter indeed has occasionally reversed its polarity, or even destroyed it entirely.

272. The intensity of the action exerted by the earth on a magnetic needle varies remarkably in different parts of its surface. As a general rule, it is less active at the equator than at the poles, and is weaker in the warmer than the colder parts of the earth. Professor Hansteen has applied the term of *iso-dynamic lines* to lines connecting the different parts of the world which act upon the magnetic needle with equal force. In their position they approach the isoclinal lines (267) already described, although they still more closely correspond to the lines of equal temperature or *iso-thermal* lines (838). The magnetic intensity is greater in the western and northern than in the eastern and southern hemispheres. Hansteen has given the following values of the terrestrial magnetic force of several places.

St. Petersburgh	1·403
Stockholm	1·342
London	1·330
Berlin	1·364
Paris	1·348
Vienna	1·325
Florence	1·278
Madrid	1·294
Rome	1·264

273. The action exercised upon the earth by a magnetic needle is not a directly attractive, but rather a directive force; for if a magnetic bar be placed on a cork, and allowed to float on the surface of a pool of water, it will not traverse it so as to reach its northern side, but will remain where it was placed, but with its poles arranged in the magnetic meridian. The bar will thus point towards both poles of the earth without evincing any tendency to move towards either. Hence the influence of the earth's polarity on a needle is *directive* not *attractive* and may be represented by two equal parallel, and opposed forces. This may be readily understood by admitting the distance of the magnetic poles of the globe to be almost infinite with regard to the needle, and thus permit their influence to be exerted on the needle in parallel

Fig. 162.

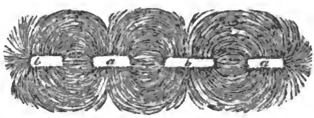


lines. For if a magnetic needle AB, be made to assume the direction GH by the application of any force, the resultant of all the forces which act obliquely

on G, to move it towards A, may be represented by GI, parallel to AC. But this force may be resolved (66) into others, one, IP, parallel, and another, IE, perpendicular to GC. On completing the parallelogram GEIP, the line GP will represent that part of the force GI, which is effective and active in moving G towards A. At the other end H, of the needle a similar application of the parallelogram of forces will also apply; the forces acting on the opposite ends of the needle in opposed directions will tend to produce similar effects, and to *direct* the needle GH into the direction of the magnetic meridian AB. This *directive* action on the needle is always *equal to the sine of the angle* made by it, with the magnetic meridian.

274. Occasionally a magnetic bar will be met with, in which magnetic properties are developed, not only at its poles, but in certain intermediate positions: this arises from an irregular disturbance of the equilibrium of the two fluids, and is generally connected with some peculiarity in the structure of the bar, or in the mode in which the decomposition of its latent and combined

Fig. 163.



magnetism is effected. In such a bar, if placed beneath a sheet of pasteboard, and iron filings sifted over it, the existence of its several poles will be demonstrated by the manner in which the filings become arranged. Thus, instead of forming two series of curves (252), as many become developed as there are poles in the bar; pointing out the position of what are called *consecutive poles*. Thus, in the above figure, *ba* are the terminal, and *ab* the consecutive poles.

275. In the foregoing remarks, the only substance mentioned as capable of assuming and presenting magnetic phenomena, is iron. It has, however, been long known that two other metals at least, nickel and cobalt, possess a similar property, although in a much less degree than iron. From some researches of Coulamb, however, it appeared probable that some organic substances were obedient to the influence of a magnet. The whole subject has lately received a vast and unexpected development in the hands of Dr. Faraday. This distinguished philosopher found that when a powerful electro-magnet (483) was employed, the following bodies were acted upon with varying intensity, and hence they must be added to the category of magnetic metals with iron, nickel, and cobalt.

Manganese.
Chromium.
Cerium.
Titanium.
Palladium.
Platinum.
Osmium.

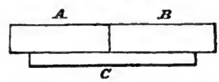
276. It was moreover discovered that the salts of these bodies were, as well as those of iron, nickel, and cobalt, obedient to the powerful electro-magnet when made into bars by filling thin glass tubes with them. Nay, their solutions were absolutely thus acted on. Green bottle-glass, crown-glass, and

even a roll of writing paper, are attracted by the magnet in consequence of their containing iron.

277. As magnetism always exists in iron, although in a latent state, it is readily excited, or in other words the combined fluids decomposed, by various processes. A bar of soft iron placed in the magnetic meridian (264), almost instantly, under the inductive influence of the earth, acting like a second magnet (256), acquires a low degree of polarity; if the iron be too close and compact to allow this ready decomposition of the magnetic equilibrium of the bar, a few blows applied at one extremity, to cause it to vibrate, will, generally, very considerably aid the inductive influence of the earth. A bar of iron heated red-hot, and allowed to cool in the direction of the magnetic dip (266), will generally be found to be magnetic, and bars of iron left for some time in this position, or one approaching to it, will acquire a low degree of magnetism: hence pokers, tongs, iron hooks, or other ferruginous bodies long kept in a position of about 70 degrees with the horizon, are always found to be more or less magnetic. A thin bar of iron, as a piece of wire, may be rendered magnetic, by forcibly twisting it until it breaks. A strong electric discharge will produce a similar effect, and even, according to some observers, exposure to the violet rays of the prism.

278. An iron bar may be rendered magnetic more readily by various processes, technically termed *touches*, all depending upon inductive action (255). The simplest mode is to pass one pole of a magnet over the whole length of a bar of iron or steel, of course always in the same direction; the end of the bar last touched by the *boreal* pole of the magnet becoming an *austral* pole. This is usually termed the process of the *single touch*. Another and convenient mode, is to join the opposite poles of two magnets AB, to place them over the centre of the bar of iron C, and to separate AB from each other, drawing them in contrary directions over C. They are then removed, again placed together, and reapplied to C, once more separated, and so on, the bar C ultimately acquiring a very energetic degree of magnetic intensity.

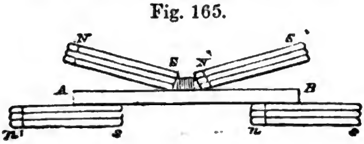
Fig. 164.



The process of the *separate touch* is somewhat similar to the last, except that the ends of the bar C, *rest* upon the opposite poles of two sets of magnetic bars made by fastening four or five together, with their poles in the same direction. A and B are, instead of simple bars, similar compound magnets, not lying on the bar C, but elevated at an angle of about twenty-five or thirty degrees; they are united and then separated by drawing them to the opposite ends of the bar C, as in the last described process.

279. In the process of Œpinus, or the *double touch* the bars are similarly placed, as in the *separate touch* last described, but the magnetizing bars are inclined at an angle of fifteen or twenty degrees, and not separated; but moved from the middle to the ends of the bar of iron backwards and forwards, commencing and ending the friction in the middle. In the following figure, AB is the bar to be magnetized, *ns* and *n's'*, the fixed magnets on which it rests, and NS, N'S' the movable magnets, kept asunder at SN' by a small piece of

Fig. 165.



wood: by this process very thick bars may be readily magnetized. The magnets employed in these processes do not give up any portion of their fluids to the bars, they are used merely to *excite* in the manner already explained (255); as each particle of magnetic fluid is firmly tied to the atom of iron to which it belongs (258), and consequently they do not suffer by the process.

280. A most excellent mode of exciting magnetism in bent steel bars is the following, the merit of which is due to Jacobi of Dresden. Let AB be the bar to be magnetized, place it on the table in contact with the poles of a horse-shoe magnet NS, then place a bar of soft iron on the poles of NS and glide it over AB in the direction of the arrow; then lift it off, replace it, again glide it, and so on. After doing this half-a-dozen times the friction should be applied to the opposite sides, and the bar will be found powerfully magnetized. Peschel succeeded, by stroking a horse-shoe of steel of one pound weight six times in this manner, in rendering it so powerfully magnetic, that it lifted with ease twenty-six pounds nine ounces.

Fig. 166.

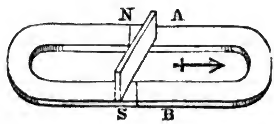
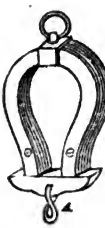


Fig. 167.



281. Magnetic bars are sometimes bent into the shape of the letter U, and are then termed *horse-shoe* magnets; and several are not unfrequently fastened together, with their similar poles in the same direction, constituting a *battery of magnets*. In this case they are peculiarly fitted for lifting heavy weights, as, by applying a bar of soft iron, A, to their poles, it becomes by inductive action (255), a magnet, and will adhere to the poles with a very considerable force. In constructing magnets, it is usual to draw, with a file, a line on that end of the bar which it is intended to convert into an *austral* pole, or that which, if freely suspended, would point towards the north pole of the earth.

282. The *coercion force* of the other magnetic metals, by which is meant their power of retaining magnetism once developed in them, especially nickel, is not so energetic as that of iron, according to the experiments of Biot. The bars used for these researches were prepared by Baron Thenard, and were as free from iron as the chemical skill of that philosopher could render them. M. Biot found that the magnetic intensity of bars of steel and nickel, of the same size, were to each other as 0·002215 to 000684, the intensity of the steel magnet being more than three times as great as that of nickel. The magnetic intensity of cobalt has not been examined so carefnlly as that of nickel.

283. A beautiful illustration of the mode of determining the intensity of forces acting on a needle, by a number of oscillations it performs in a given time, is found in the demonstration of the law of intensity of magnetic action, for which, among a host of other invaluable investigations, science is indebted to M. Coulomb. A small needle suspended by a single thread, and protected from the influence of aërial currents, performed fifteen oscillations in one minute; let the directive force (231) of the earth producing these be called

m. A long steel magnet placed in *the magnetic meridian*, had one pole approached to the distance of four inches from the needle, the latter made forty-one oscillations in one minute; the force thus exerted may be called m'. On removing the pole to eight inches from the needle, the latter made twenty-four oscillations in the same time; this force may be represented by m''. The action of the magnet on the needle, in the first experiment, is $m'-m$, and in the second $m''-m$, because its effects resulted from its own force *plus* the attraction of the earth, thus,

$$\frac{m'-m}{m''-m}=\frac{41)^2-(15)^2}{24)^2-(15)^2}=\frac{1456}{351}=4{\cdot}148\,;$$

here, in the second experiment, when the distance of the needle from the pole was twice that of the first experiment, the magnetic intensity was found to be diminished, as nearly in accordance with the law, of its being inversely as the squares of the distances, as experimental investigation could be expected to approach.

284. Magnets, if left to themselves, gradually and in a space of time varying with the hardness of the metal composing them, lose their magnetic properties, from the recombination of the separated fluids. This is prevented by keeping their poles united, by means of a piece of soft iron, which, becoming magnetic by induction, reacts on the magnetism free in the poles of the magnetic bar, and tends to increase instead of diminishing their intensity. This *coercing* force becomes remarkably diminished by raising the temperature of a magnetic bar. If a magnet be heated to 100°, it appears to lose much of its attractive power, but recovers it on cooling. But if the bar be heated to redness, and then cooled, it will be found to have lost all traces of magnetism. On the other hand, the power of a magnet appears to increase with its diminution of temperature to an almost indefinite extent. In the weakly magnetic metals, their power becomes remarkably increased by exposing them to a temperature below zero. If a ball of iron be heated to whiteness, it ceases to have any action on a magnet needle held near it. Nickel, at a temperature of 630°, acquires a similar passive state.

285. Artificial magnets have been constructed by reducing to powder the native magnetic oxide of iron, and forming it into bars with wax and oil. They may also be constructed by forming the artificially prepared black oxide of iron, into bars with wax, and magnetizing them by one of the processes already described.

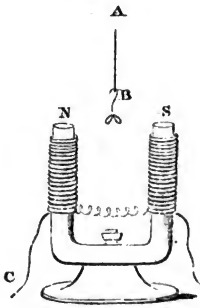
A great number of mineral and even organic matters appear, from the researches of Coulomb, to be capable of assuming a faint and transient degree of polarity. And when studying the science of electro-dynamics we shall learn that all metals under the influence of electric currents are capable of acquiring well-marked magnetic properties (470).

286. Hitherto, when a body, not itself possessing magnetic properties, has been alluded to as obedient to the action of the magnet, we have found that it is equally *attractive* by both poles. Thus when a bar of soft iron is suspended over the poles of a horse-shoe magnet, so as to be free to move, it attains a state of rest in a position parallel to a line connecting both poles, or in the direction of what has been aptly called the lines of magnetic force; the cause of which may be rendered obvious enough by sifting iron filings over a piece of card-board resting on the poles (252). Dr. Faraday, however, discovered the remarkable fact that a vast number of bodies are mutually *repelled* by both poles. And thus, when formed into bars and suspended by means of a long and slender thread between the poles of a powerful magnet, they vibrate, and ultimately come to rest in a line equi-distant from both

poles, and perpendicular to the lines of magnetic force. A direction, consequently at right angles, to that taken by a bar of iron. As this power, although obvious enough, is still far weaker than the attractive power exercised on iron, some little management is necessary to render it evident.

287. The best apparatus for this purpose consists of an electro-magnet (483), both because of the immense power which may be communicated to it, and of our being able to reverse or destroy its polarity at will.

Fig. 168.



An electro-magnet NS, capable of holding a bar of iron on either pole with a force of at least fifty or sixty pounds, should be firmly fixed to a wooden support. From the ceiling of the room a slender thread AB, should be suspended, having attached to its lower end a double hook or cradle of thin copper wire. The substance to be examined should be made into a bar, or, if in powder or solution, placed in a thin glass tube, and carefully allowed to rest in the little cradle. A cylinder or case of glass ought, in many cases, to be placed round the apparatus to prevent the interference of currents of air. The wires CZ of the coil surrounding the iron bars should then be connected with the battery. The iron bars instantly become powerfully magnetic, and the body placed in the cradles will either be attracted by both poles and assume a corresponding position, or be repelled by both, taking up a position at right angles to a line connecting them; or, lastly, be quite unaffected. A bar of iron will illustrate the first condition, one of bismuth the second, and a tube full of air the third.

288. These bodies which are attracted, however feebly, by the poles Dr. Faraday proposes to call *magnetic* according to general custom, those which are repelled he terms *dia-magnetic*; whilst those which obey neither force are regarded as *indifferent*.

289. The first substance in which these new *dia-magnetic* properties were detected was a heavy glass, composed of silicated borate of lead. A bar of this two inches long and half an inch thick was suspended between the poles (287) and allowed to come to rest. As soon as the bar was quite quiet, the wires CZ of the apparatus were connected with a battery of ten pairs on Mr. Grove's construction (420). The bars instantly became powerfully magnetic, and the piece of glass as quickly moved away from both poles round its point of suspension, and took up its position at right angles to a line connecting the poles. The position of the piece of glass was uninfluenced by reversing the magnetism of the bars, being always repelled by both poles under all circum-

stances, so that it might be regarded as a magnet pointing east and west, in relation to the north and south poles of the electro-magnet. If but one pole of the magnet be employed, the same repulsive action is exerted, although of course with less energy.

290. To produce the effect of pointing across the lines of magnetic force, the form of the *dia-magnetic* body must be long. A cube or sphere will not thus point, but two or three placed side by side in a paper tray will. But portions of any shape are repelled. Thus, if two fragments be suspended between the poles parallel to each other, they will appear to attract each other, in consequence of being simultaneously repelled by both poles.

291. Flint-glass is similarly acted upon by the magnet, but not so powerfully as the heavy glass. Cylinders of phosphorus, sulphur, and caoutchouc are readily affected by the magnet. A large number of crystaline bodies as well as ether, alcohol, oils, water, and blood, when inclosed in tubes, were all found to be dia-magnetic, and to become repelled. Animal flesh is thus acted upon; hence, as Dr. Faraday has observed, if a man were suspended over the poles of a sufficiently large magnet, he would be repelled, and point east and west.

292. Among the metals, the following were found to be most energetically *dia-magnetic* in the order in which they are placed.

Bismuth.
Antimony.
Zinc.
Tin.
Cadmium.
Mercury.
Silver.
Copper.

Bismuth is very readily thus acted upon, and a small bar of it, two inches long and half an inch wide, is peculiarly fitted for the exhibition of the phenomena now described.

293. The fact of salts of the magnetic metals obeying the attractive action of a powerful electro-magnet has been already alluded to (276). In the case of iron, some curious and highly interesting anomalies were observed, evidently connected with the constitution of the salt. Thus the chlorides, iodides, sulphates, phosphates, chromates of iron, and even Prussian blue, all obeyed the attraction of the magnet, whilst the yellow and red prussiates of potass, in which the iron does not play the part of a base, were repelled and appeared *dia-magnetic.* A fine illustration of the relation between the force of magnetism and the molecular constitution of a salt.

Dr. Faraday placed solutions of protosulphate of iron in thin glass tubes, and so suspended them that they could be immersed in glass vessels placed between the poles of a very powerful electro-magnet. He thus discovered, that when a tube was filled with the solution of iron, and immersed in a solution of iron of the same strength, it was utterly indifferent to the action of the magnet. When immersed in a much stronger solution, it was repelled like a *dia-magnetic*, and when in a much weaker solution attracted like a *magnetic* body. Water being a dia-magnetic (288), and sulphate of iron magnetic, a solution can be prepared of such strength as when suspended in the air to be absolutely indifferent to the action of a magnet.

294. The following list is given by Dr. Faraday* as giving a view of the intensities with which different bodies exhibited magnetic and dia-magnetic phenomena.

* Phil. Trans., 1846.

Magnetic.........	Iron.
	Nickel.
	Cobalt.
	Manganese.
	Palladium.
	Crown-glass.
	Platinum.
	Osmium.
	Arsenic.
Indifferent........	Air and Vacuum.
	Ether.
	Alcohol.
	Gold.
	Water.
	Mercury.
	Flint-glass.
	Tin.
	Heavy-glass.
	Antimony.
	Phosphorus.
Dia-magnetic.....	Bismuth.

295. It is really difficult to guess at the limit which may exist to the power of magnetism in controlling or influencing molecular forces. The elaborate investigations of Dr. Faraday have opened out a field of rich promise. A force which a few years ago was supposed to influence pieces of iron only, is by these researches shown to act upon almost every form of ponderable matter. It is perfectly true that La Baillif some years ago ascertained that pieces of bismuth and antimony acted on the magnetic needle, and that Coulomb made a similar statement regarding many organic substances. But neither of these philosophers followed up their observations, and to our own distinguished countryman is due all the merit of the important discoveries of which I have given an outline.

296. There are some few remarks on record respecting the influence of magnetic polarity on the reduction of metals and crystalization, hitherto regarded as but of little importance, but the discoveries of Faraday make all such statements now matters of interest, and render a further investigation of them necessary. Berzelius states, on the authority of Hansteen and Maschmann, that when the centre of a U shaped tube is filled with mercury, and a solution of nitrate of silver poured into either leg, the reduction of the silver and growth of the *Arbor Dianæ* take place equally in either leg when they are placed respectively east and west. When, however, they are placed parallel to the magnetic meridian, the silver is reduced in greater abundance in the northern leg. Murray has stated that when iron wires are placed in weak solutions of nitrate of silver, no change takes place, but the silver is reduced immediately the wires are rendered magnetic by bringing near them the poles of a powerful magnet. Another curious statement has been made by Ludecke, that when a glass vessel containing a concentrated solution of salt is allowed to rest on the poles of a powerful horse-shoe magnet, the crystals which form will be collected at the bottom of the glass in every part, except a space corresponding to the two poles and the magnetic field between them. Ludecke mentions solutions of acetate of load and sal ammoniac as readily exhibiting this phenomenon. This might be explained by regarding them as dia-magnetic, had he not also stated that sulphate of iron presented the same effect, which salt being magnetic would not permit of the same explanation.

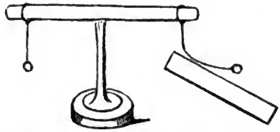
CHAPTER XI.

ELECTRICITY. (PRIMARY PHENOMENA.)

Excitation, 297. *Attraction and Repulsion*, 298. *Conductors, Insulation*, 300. *Natural state of the two Electricities*, 303. *Electroscopes, or Electrometers*, 304. *Coulomb's balance*, 307. *Excitation of different substances*, 308. *Spark*, 311. *Superficial diffusion of free Electricity*, 313. *Induction*, 316. *Electrophorus*, 322. *Electric tension*, 324. *Electrostatic Laws*, 326.

297. If a thick glass tube, previously made dry and warm, be briskly rubbed, for a few seconds, with a piece of silk or woolen cloth, also dry and warm, and then held near small pieces of paper or cork, placed on the table, these light substances will be attracted by the *excited* tube, and leap towards it. After adhering to its surface for a short time, they will be repelled towards the table, after touching which, they will be again attracted by the tube; and these phenomena will be repeated, until the properties excited by the previous friction on the surface of the glass vanish. A piece of amber, sulphur, or sealing-wax, after *excitation* by a woolen cloth, will exhibit the phenomenon of attracting light bodies, like the glass tube.

Fig. 169.



298. Suspend a light ball of pith of elder, or cork, by a long silken thread from the ceiling, or any convenient support, and approach towards it an excited glass tube, the ball will be attracted, and after adhering for a short time to the tube, will be repelled to a considerable distance, nor will it be again attracted until it has touched some substance connected with the earth, and thus lost the peculiar properties it had acquired by contact with the tube.

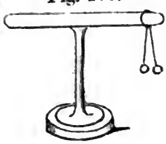
Whilst the pith ball is thus repelled by the tube, bring towards it an *excited* piece of sealing-wax, it will instantly be attracted by it, soon, however, becoming repelled, when it will rush towards the glass tube, if held sufficiently near. It will thus vibrate like a pendulum between the excited glass and sealing-wax, being alternately attracted and repelled by each.

299. From these simple experiments we learn that certain bodies acquire by friction properties of which they were previously destitute, which properties become readily manifested by the attraction and repulsion of light bodies. As these phenomena were first observed in pieces of amber (ἤλεκτρον) the term *electricity* has been applied to the properties thus excited. We also, from the observations just made, learn that the electricity excited by the friction of glass is communicated to pieces of paper, or pith balls, placed in contact with it, and that the bodies thus acquiring electricity are repelled by the tube, until after they have given up their acquired electricity to some body brought in contact with them; and as, when thus repelled by excited glass, the ball is attracted by excited resins, we have fair and valid reasons for concluding that the electricity developed in these substances by friction consists of two different species or kinds. That which is acquired by excited glass is termed the *vitreous* or *positive* electricity, and that by excited amber, wax, and resins, the *resinous* or *negative* electricity. We learn, moreover, *that bodies pos-*

sessing one kind of electricity are attracted by those possessing the opposite kind, and repelled by those possessing the same kind. A substance possessing either species of electricity in a free state is said to be *electrified; negatively*, if its electricity be negative; and *positively*, if it be positive.

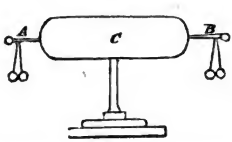
300. In consequence of the wax, glass, &c., in the preceding experiments, acquiring electricity by friction, they are said to be *idio-electric*, whilst those not possessing this property, as metals, are termed *anelectrics*. From the general law of bodies, similarly electrified, repelling each other (299), we acquire a very convenient mode of detecting the presence of free electricity: instead of a single pith ball (298), use two, fixed one to each end of a piece of thread; and hang this by the middle across a fit support. On touching this little apparatus with the excited tube or sealing-wax, electricity will be communicated to it, and the balls being similarly electrified, will repel each other, and separate to a considerable distance, forming the simplest kind of electroscope or indicator of free electricity.

Fig. 170.



301. Insert into either end of a hollow cylinder of tin, C, supported by a glass leg, a wire or rod of metal, as brass, B, and one of glass or sealing-wax, A, and suspended from each a pair of pith balls, fixed to thread or cotton. Then touch the middle of the cylinder C with an excited glass tube; immediately the pith balls suspended from the brass rod B will separate from each other, whilst those suspended from the glass A will remain unaffected. This curious phenomenon arises from certain bodies, as metals, cotton, thread, &c., possessing the property of *conducting* electricity; whilst others, as wax, glass, silk, &c., are incapable of being traversed by it. On this account, bodies have been divided into two great groups; *conductors* and *non-conductors* of electricity; the former being in general identical with *anelectrics*, and the latter with *idio-electrics* (300). The line of demarkation between these two great classes is by no means strictly definable, as a large number of substances exist which conduct electricity when present in large quantities, and insulate (302) it when in small; or whose conducting powers vary with their temperature.

Fig. 171.



302. Among conducting bodies may be ranked all metals, charcoal, water, steam, all animal and vegetable substances containing water, and many other substances; whilst glass, and all vitrifactions, gems, resins, sulphur, metallic oxides, organic substances perfectly free from water, and ice, are all more or less perfect non-conductors and idio-electrics. A substance supported by a non-conductor, as when placed upon a stool of glass legs, is said to be *insulated*, from its electric connections with the earth being separated.

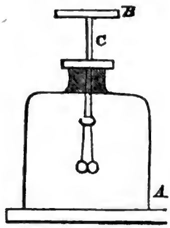
303. Electric matter is universally present in nature, but in a latent state; the reason of which latter circumstance, the preceding observations will enable us to understand. The two species, or negative and positive electricity, exist in nature *combined*, forming a neutral combination, in an analogous manner to the two magnetic fluids (258), incapable of exerting any obvious physical action on ponderable matter. By the process of friction, or other mechanical or chemical means, we decompose this neutral combination, the negative and positive elements separate, one adhering to the surface of the excited substance, the other to the rubber; hence, in no case of electrical excitation can we obtain one kind of electricity, without the other being simulta-

neously developed. And all electric phenomena, from the simple ones just described, to those of a more brilliant character, which we shall presently examine, are referable to the mutual attraction of the two separate electric fluids for each other; by which they attempt to combine whenever they have been artificially separated. There is an essential distinction between the properties of the magnetic and electric fluids connected with their different relations to ponderable matter. Thus, if we admit the existence of a magnetic fluid at all, we must grant that it is necessarily firmly united to each molecule of ponderable matter; so that although we can disturb the magnetic equilibrium of an atom, we cannot disperse its magnetism among other atoms. Whereas in the case of electricity we can sever the two electric elements, and in appearance, at least, compel them to separate to a considerable distance, in different masses of matter, as shown by the phenomena of induction. We do not observe any free electricity on the surface of metallic bodies submitted to friction unless carefully insulated, in consequence of their so readily conducting electricity, that the re-union of the negative and positive fluids takes place as rapidly as they are separated by the friction employed.

Both forms of electric matter, separately, produce precisely the same physical effects on bodies, differing only in their properties in relation to each other. These electricities, although frequently called fluids, have but little claim to that designation; in using it, therefore, let it be always understood in a conventional sense, not as expressing any theoretical view of the physical states of electric matter.

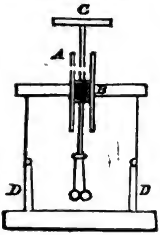
304. Certain pieces of apparatus, termed electrometers, or more properly electroscopes, are constantly called in requisition, in prosecuting the study of electric science; the pair of pith balls already described (300) are frequently called by this name, and employed to detect the presence of free electricity. As the currents of air always moving in the atmosphere, render the indications of the pith balls obscure, they are frequently suspended by linen threads to a metallic rod fixed in the neck of a glass bottle or cylinder, A. On touching the top B of the apparatus with an excited piece of glass or resin, the electricity is diffused along the metallic rod C, in consequence of its being a good conductor, and reaching the pith balls, they, becoming similarly elctrified, repel each other (298), and by their repulsion the presence of free electricity is indicated. The electric fluid does not escape from the rod C to the earth, in consequence of the glass jar supporting it being a non-conductor, and therefore acting as an insulator (302).

Fig. 172.



The electricity thus acquired by the pith balls gradually disappears by its becoming neutralized by acquiring from the circumambient air, the electricity of the opposite kind to that with which it is charged. If the outside of the glass vessel in which the pith balls are suspended, be moist, they will still more rapidly lose their electric state, in consequence of their acquiring from the earth the opposite electricity, and thus having their natural electric equilibrium restored. For this reason it is absolutely necessary to carefully dry the exterior of the glass vessel, to insure the success of an experiment. To prevent the deposition of moisture on this as well as all other pieces of electric apparatus, it is usual to cover the upper part of the glass externally with a solution of shell lac in alcohol; this, on drying, leaves a nearly transparent covering of an excellent insulating substance, which is less liable to attract moisture from the air than the naked glass.

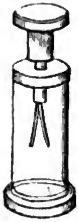
Fig. 173.



305. The best electrometers are generally furnished with a contrivance invented by the late Mr. Singer. In this arrangement the metallic rod to which the pith balls are attached, passes through a glass tube, covered both externally and internally with lac varnish; this rod is retained in its place at B by a plug of silk, lac or other non-conducting substance; the advantages of this contrivance are sufficiently obvious, for it is evident that any electricity communicated to the rod C, cannot be neutralized excepting from the air, until the whole of the interior of the tube A, and the outside of the apparatus becomes covered with moisture. I have repeatedly found such an instrument perfectly sensible to mere traces of electricity, after having remained unused, and even covered with dust, during six months.

As it is often necessary to discharge these instruments of all the electricity communicated to them, two slips of tin-foil DD are usually fixed along the inside of the glass case of the instrument, so as to touch its base, which for this purpose must be of metal or some good conductor. On communicating electricity to such an electrometer, the pith balls separate, and, striking the slips of tin-foil, thus become readily unelectrified.

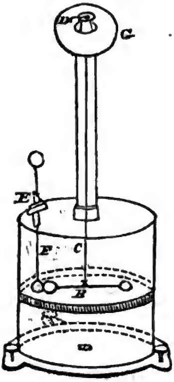
Fig. 174.



306. When we have occasion to detect any minute quantities of electric matter, the weight of the pith balls in the last described electrometer interferes too much with the delicacy of the instrument; on this account two slender slips of leaf-gold, hanging parallel to each other, are with great advantage substituted for the pith balls. A gold-leaf electrometer, with Singer's mode of insulation (305), furnishes us with the most delicate instrument for the detection of small quantities of electricity which has yet been contrived.

307. All the instruments above described, merely indicate the *presence*, and not the *quantity* of electricity present in any substance in a free state. For a mode of gaining an approximation to the knowledge of proportion of electricity, we are indebted to the sagacity of M. Coulomb, whose torsion balance well fulfills the expectations of its contriver. It consists of a slender beam, B, formed of a filament of lac, furnished with a gilded pith ball at one end, and a little vane of paper at the other. This is suspended by a fine metallic wire, C, or still better, by a filament of spun glass, in the middle of a cylindrical, or square cages of glass. The upper end of this wire, or glass thread, terminates in a key, D, furnished with an index, the whole capable of moving in the centre of a circle, G, graduated into 360°; through a hole, E, at the top of the glass cage, a rod of lac, F, terminating in a gilded ball, is inserted; being prevented falling in by a stop at E. This ball is generally termed the *carrier-ball*, on account of its being used to convey the electricity of an excited body, to the electrometer, so that its tension may be examined. To use this instrument to detect the presence of free electricity, the rod F is removed, and its ball brought in contact with the substance whose electricity is to be examined; the

Fig. 175.



ball acquires some of the free electric fluid, and on being placed in the glass cage, it shares its electricity with the ball terminating the horizontal needle, B. The two being similarly electrified, repel each other; and as F is fixed, B necessarily moves, and describes a certain angle, which it retains until it loses its electricity: to measure the quantity of fluids thus acquired, the key D, to which the glass thread C is fastened, is turned round, until, by the torsion, or twisting of the thread, the ball of B is compelled to come in contact with that of F. The number of degrees described by the index fixed to the revolving key, D, gives us an approximation to the proportion of electricity acquired by the ball of F, during its contact with an electrified body.

308. It has been already stated, that in no instance can one kind of electricity be excited without a corresponding portion of the other being set free; it being utterly impossible to obtain one electric fluid in a perfectly free state without evolving an equivalent quantity of the other, as we are taught by the phenomena of induction (315). In the present state of our knowledge, no general rule can be given as to what form of electricity is acquired by the friction of different substances, further than what data the results of experiments on this subject have furnished us with. Many substances, excited or rubbed by one rubber, evolve negative, and when submitted to the friction of another composed of a different material, evolve positive electricity; thus, smooth glass becomes positively electrified, when rubbed by flannel or silk, and negative when excited by the back of a living cat. Sealing wax, on the other hand, becomes positive when rubbed by metallic substances, and negative by almost everything else. A very useful table, exhibiting the results of numerous experiments, has been given by Cavallo:

Substances excited.	Kind of Electricity.	Material forming the Rubber.
Back of a cat	Positive	Every substance hitherto tried.
Smooth glass	Positive	Do., except the back of a cat.
Rough glass	Positive	Dry oiled silk, sulphur, metals.
	Negative	Woolen-cloth, paper, wax, human hand.
Tourmaline	Positive	Amber; a current of air.
	Negative	Diamond, the human hand.
Hare skin	Positive	Metals, silk, leather, hand.
	Negative	Other finer furs.
White silk	Positive	Black silk, metals, &c.
	Negative	Paper, hand, hair, &c.
Black silk	Positive	Sealing-wâx.
	Negative	Furs, metals, hand.
Sealing-wax	Positive	Metals.
	Negative	Furs, hand, leather, cloth, paper.
Baked wood	Positive	Silk.
	Negative	Flannel.

309. Dr. Faraday submitted the following bodies to friction, and found that any one of them became negative with the substances above and positive with those beneath.

1. Catskin or bearskin.
2. Flannel.
3. Ivory.
4. Quill.

5. Rock-crystal.
6. Flint-glass.
7. Cotton.
8. Linen, canvas.
9. White silk.
10. The Hand.
11. Wood.
12. Lac.
13. Metals.
14. Sulphur.

The mode of rubbing often makes a remarkable difference; thus, a feather merely brushed against a piece of canvas will be negative, whilst if drawn forcibly between its folds it will be positive. Two pieces of flannel drawn across each other will possess different electric states, according to the direction of the friction.

310. Electricity is not only set free by friction, but by almost every form of mechanical change to which any substance can be submitted; mere pressure is quite sufficient for this purpose. Take two pieces of common window-glass, each presenting a surface of about four square inches, to the centre of each fix a piece of sealing-wax, to serve as a handle; press the discs firmly together, and, whilst in this state, approach them to a gold-leaf electrometer (306), no divergence of the slips of gold will ensue: but suddenly separate the pieces of glass, and bring one of them near the electrometer, and the instant separation of the gold leaves will demonstrate the presence of free electricity in the discs, one of which will be found positively, and the other negatively electrified. Sulphur poured, whilst melted, into a conical glass, and furnished with an insulating handle, as a piece of glass or silk, will, when cold, indicate no free electricity, until the cone of sulphur be lifted from the glass, and then the former will be found negatively, and the latter positively electric. On tearing asunder pieces of cloth, suddenly separating a pair of dry and warm silk stockings which have been rolled up together for some time, or rapidly unfolding a roll of flannel, we have abundant evidence of the evolution of free electricity as shown by the action of these bodies on electrometers, and even by their evolving flashes of light and sparks (312).

311. Certain minerals, aspecially tourmaline, and many of the family of zeolites, have their neutral and latent electricity decomposed and developed by heat, one extremity of the crystal becoming negative, and the other positive. When a prism of tourmaline is greatly heated at one extremity, its electricity becomes decomposed, the negative passing to one, and the positive to the other end of the crystal; signs of free electricity gradually increasing as we advance from the middle, where they are absent, towards either extremity of the prism. The distribution of electricity being strikingly analogous to that of magnetism in a magnet, according to the hypothetical formula of Eschenmaier (259), which, setting e with the positive co-efficients for *positive*, and with the negative for *negative*, &c., electricity; will stand as applied to the heated tourmaline, thus,

$$e^n \ldots\ldots\ldots e^3\, e^2\, e^1\, e^0\, e^{-1}\, e^{-2}\, e^{-3} \ldots\ldots\ldots e^{-n}.$$

It may be stated that, in general, no idio-electric substance (300) can be pressed, bruised, rubbed, or submitted to a change of temperature, without suffering some decomposition of its neutral and latent electricity; one or the other kind being developed in a free state in the body, in greater or less proportions, according to circumstances.

312. If the excitation of the glass tube (297) be performed in a darkened room, a pale lambent flame will be observed on its surface, each time the tube is drawn through the piece of silk, accompanied by an odor like that of phosphorus; and on bringing the glass near any conducting body, as the hand, a small but vivid spark will be observed to pass between them, attended with a faint, but sharp, crackling noise. The evolution of this electric light was

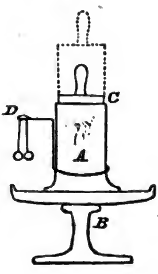
first distinctly noticed by Otto de Guericke, at the latter end of the 17th century, whilst submitting a globe of sulphur to the friction of the hand; about the time, Boyle observed the light emitted by an *excited* diamond; and Dr. Wall, that given off from a piece of *excited* amber, on the approach of the finger.

This electric light can be easily observed by drawing a piece of dry and warm brown paper, about eighteen inches long and four broad, through a piece of warm flannel; on bringing the hand near the paper, as it is rapidly withdrawn from the folds of the flannel, bluish flashes of light, two and three inches in length, will be darted off in various directions, accompanied by a loud crackling noise.

313. Electricity thus excited in, or communicated to any substance, does not appear to penetrate into the interior of the mass to any extent, but to reside almost exclusively upon its surface Coulomb found that, on suspending, by silken threads, a conducting body, in which various pits and depressions had been made, and communicating to it some electricity from an excited tube, the carrier-ball of his electric balance (307) being applied to the bottoms of these cavities, gave no sign of free electricity on being placed in the electrometer; although, when brought in contact with the surface of the conductor, it became strongly electrified; proving that electricity is almost entirely limited to the surfaces of insulated bodies. This circumstance is, as Dr. Faraday has shown, easily explained by the inductive influence of the electricity present in surrounding objects, and even in the comparatively distant walls of the room. This most talented and excellent philosopher, among other experiments, made with a view of obtaining some light on this matter, constructed a room of a light frame-work covered with canvas. This was carefully insulated, and Faraday entered it. On being connected with the conductor of a powerful electric machine, it appeared so highly electrified, that flashes of light darted off from the outside of this insulated room towards the walls of the apartment containing it, and yet no appearance of free electricity could, during this time, be detected in its interior.

314. As a necessary consequence of this law, we find that, the quantity of electricity remaining the same, its effects on the electrometer become diminished, by increasing the surface to which it is confined.

Fig. 176.



A hollow tin cylinder A, about eight inches in length, is insulated by a glass support B: an inner tin cylinder C, provided with a glass handle, moves readily in the outer one: from the latter passes a curved wire D, to which a cork-ball electrometer is suspended. Now, touch A with an excited glass tube, the electricity diffusing itself over the apparatus, will cause the pith balls to become electrified, and consequently repel each other. When these balls are about one third of an inch apart, raise the inner cylinder C, by its glass handle, as high as possible without entirely removing it from A; the electricity will be expanded over twice its previous superficial extent, and a smaller quantity will be left in the pith balls, which will consequently approach each other. Then depress the inner cylinder C, the electricity will again be spread over a lesser surface, and the pith balls will separate as at first.

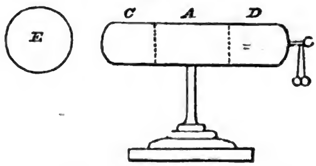
315. A simple and more effective mode of demonstrating the same fact, is

Fig. 177.

to insulate a small cup of tin or other metal, having a wire fixed to its exterior, carrying a pair of pith balls. A piece of thick brass chain having a silken string tied to one end is placed in the cup. On giving the latter a spark from an excited glass tube, the pith balls will diverge, then raise the chain by means of the silken string, so that ten or twelve inches of it are out of the cup. The pith balls will immediately collapse; return the chain and they will again diverge and so on.

316. Let CAD be a conducting body, as a cylinder of tinned iron, placed on an insulating support; a cork ball electrometer F, being suspended from one end of the cylinder. Now *approach* any positively electrified body, E, as an excited tube, about six inches from C, the pith balls F will instantly separate, indicating the presence of free electricity.

Fig. 178.



This could not arise from any electric fluid having passed from E to C, as on removing E to a considerable distance, the balls F will fall together, and appear unelectrified; on again approaching E to C, the balls will again diverge, and so on. This very curious phenomenon arises from the positive electricity in E, decomposing the neutral and latent combination (303) in CAD, attracting the negative towards C, and repelling the positive electricity towards F; and the balls consequently diverge, being positively electrified. On removing E, the force which separated the two electricities in CAD, is removed, and the separated elements reunite, neutrality is restored, and the pith balls fall together. The action exercised by E, is called *induction*, from the electricity it contains, *inducing* a change in the electric state of DC. It is convenient also to follow Dr. Faraday in calling the tube E, whence the induction is exerted, the *inductive*, and the cylinder CAD, whose electric equilibrium is thus disarranged, the *inductric* body.

316*. If the cylinder CAD, be carefully examined whilst within the inductive influence of the positively electrified ball, E; the end C, will be found to be negatively electric, and the end D, positively, whilst an intermediate zone, A, will be found to be neutral and unelectrified. So that the distribution of electricity on the surface of the cylinder may be compared to that in an excited tourmaline (311). Whilst things are in this state, and the pith balls standing apart from each other, touch the cylinder DC, with the finger, or any other conducting body connected with the earth; the pith balls will collapse, from the positive electricity running off by the finger to the earth. The negative electricity cannot escape in the same manner, because it is firmly held in the end C, of the cylinder, by the attractive influence of the opposite electricity of the ball, E. Now remove the finger, leaving the conductor insulated, and separate E, to a considerable distance from C; the negative electricity in

which, being released from the influenee of E, expands itself over, DC, and the positive electricity which had been previously combined with it having been removed by previously touching it with the hand, and the balls F instantly separate with *negative* electricity. If this experiment be repeated with an *excited* piece of sealing-wax, amber, or sulphur, instead of the glass tube, E, the same phenomena will occur, with this difference, that the induced electricity will always be of the opposite kind, as would, of course, be expected *à priori*.

317. The application of this inductive influence, furnishes us with the readiest mode of ascertaining the kind of electricity present in any excited substance. For this purpose, excite a glass tube by friction, and hold it about a foot distant from the cap of the gold-leaf electrometer (306); the leaves will diverge with positive electricity, the negative being retained in the cap of the instrument. Touch the latter with the finger, the leaves collapse, and the *positive* electricity escapes to the earth; the *negative* being retained in the cap by the attraction of the positively electrified tube. Now, remove first the finger, then the tube, and the gold leaves will diverge with *negative* electricity. Excite, by friction or otherwise, the substances whose electric state is to be examined, and hold it near, but not in contact with, the cap of the electrometer; if the substance be positively electrified, it will attract the negative electricity from the gold leaves into the cap of the instrument, causing them to collapse; whilst, if it be negative, it will, by repelling the electricity of the same kind already in the electrometer, increase the previously divergent state of the gold leaves. By this process, it becomes exceedingly easy to discover what species of free electricity is present in any excited substance.

318. In these experiments (315—16), the induction takes place through the column of air separating the excited tube from the conductor (315), or electrometer (317). A similar action is capable of taking place when other non-conductors are interposed; these substances, in consequence of their permitting induction to take place through them, have been termed *dielectrics*. Dielectrics differ considerably in the degree of facility with which they permit induction to take place through them, indicating the existence of a specific inductive capacity. Thus, sulphur, lac, and glass, have much higher inductive capacities than air.* The following table contains the results of Sir Snow Harris's experiments on the comparative inductive powers of several dielectrics.

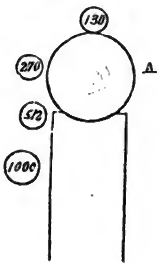
	Spec. inductive capacity.
Air	1·00
Rosin	1·77
Pitch	1·80
Wax	1·86
Glass	1·90
Sulphur	1·93
Shell lac	1·95

319. Induction has been demonstrated by Faraday, to be essentially a physical action, *occurring between contiguous particles, never taking place at a distance, without polarizing the molecules of the intervening dielectric; causing them to assume a peculiar constrained position, which they retain so long as they are under the coercing influence of the inductive body.* Thus, in the experiment already detailed (316), a space of six inches existed between the *inductive* excited tube and the inductric cylinder, whose electricity was affected by its action. We are not to assume from this, that the disturbance of the natural electric

* On this subject the admirable papers of Dr. Faraday, in the Philosophical Transactions for 1838, should be consulted, especially § 1252--78.

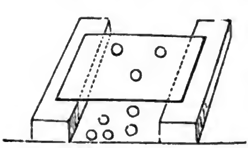
state of the conductor arose from an action at a distance; for most satisfactory evidence has been adduced by Dr. Faraday that the intervening dielectric, air, has its particles of electricity arranged in a manner analogous to those of the conductor DC, by the inductive influence of the glass tube. The theory of induction depending upon an action between contiguous molecules is supported by the fact, which would be otherwise totally inexplicable, that a slender rod of glass or resin, when excited by friction and placed in contact with an insulated sphere of metal, is capable of decomposing the electricity of the latter by induction, most completely, even at the point of the ball equidistant from the rod, and consequently, incapable of being connected with it by a right line. Dr. Faraday excited negatively a cylinder of shell-lac an inch in diameter, by rubbing it with a piece of warm flannel; and placed on its top which was cut concave for the purpose, a large brass ball A. It is obvious that the electric equilibrium of this ball must become disturbed by the inductive influence of the excited lac, its lower half becoming positive and upper half negative. If, then, A be touched with the finger, the negative electricity is discharged, and it remains positive, like the cover of an electrophorus (332). If then the carrier-ball (307) of Coulomb's torsion balance electrometer be placed in any of the various positions shown by the figured circles in the marginal wood-cut, and then returned to the balance, the force of torsion required to restore the horizontal beam of the instrument to its proper position, will give accurate information of the inductive force exerted by the lac-cylinder. Wherever the carrier-ball is placed, both it and A must be first uninsulated and then insulated, before removing it to the electrometer. The figures in the cut show the comparative amount of inductive influence exerted by the cylinder in different positions. Thus, at the top of the ball, A, the carrier-ball received a charge of positive electricity of 130° by induction from the cylinder. So that we must either consider that induction is exerted in curved lines, or propagated through the intervention of contiguous particles. Now, as no radiant simple force can act in curved lines, excepting under the coercing influence of a second force (63), we are almost compelled to adopt the view of induction acting through the medium of contiguous particles.

Fig. 179.



320. This inductive action appears to come into play in every electric phenomenon; thus, in the simple experiment of attracting light bodies by an excited tube, (297,) the positive electricity in the tube decomposes by induction the electricity of the pieces of paper, repelling their positive fluid; and being thus left in a negative state, they become attracted by the tube, in obedience to the law of mutual attraction between different electrified bodies. The following experiment illustrates in an interesting manner the development of electricity by induction. Support a pane of dry and warm window-glass about an inch from the table, by means of two books or blocks of wood; and place beneath it several pieces of paper or pith-balls. Excite the upper surface by friction with a silk handkerchief, the electricity of the glass becomes decomposed, its negative fluid adhering to the silk, and its positive to the upper surface of the glass plate; this by induction acts on the lower surface of the glass, repelling its positive electricity and attracting its negative, the interven-

Fig. 180.



ing dielectric becoming polarized in the manner already explained. The lower surface of the glass, thus becoming electrified by induction through its substance, attracts and repels alternately the light bodies placed beneath it in a similar manner as the excited tube (297).

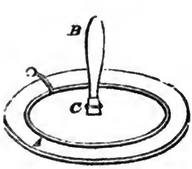
321. All cases of electrical repulsion are also really referable to attraction under inductive influence. Thus it has been stated, that two pith-balls similarly electrified repel each other. This repulsion, however, is really the effect of the attraction of surrounding bodies whose electric equilibrium is disturbed by the inductive influence of the pith-balls.

If an electroscope be constructed with two large pieces of gilded paper instead of gold-leaf, and be then electrified positively, they will present mutual repulsion. But if the carrier-ball of the balance electrometer (309) be placed in contact with the opposed repelling surfaces of the gilded paper, it will not, when removed, possess any trace of free electricity, whilst from the other surfaces a powerful positive charge can be obtained. The slips of paper repel each other, in appearance only, being really attracted by the sides of the case containing them, or even by very distant objects, as the walls of the room whose electric equilibrium becomes disturbed by the inductive influence of the free surfaces of the slips of paper. A similar explanation applies to every case of electric repulsion.

322. Induction takes place through a thin plate of a perfect conductor, as readily as through a non-conducting dielectric. A thin piece of gold-leaf may, by the inductive power of an excited electric, become intensely positive on one side, and as powerfully negative on the other, as long as it is within the influence of the inductive body.

Into a circular tray of tinned iron, A, about eight or ten inches in diameter and one inch deep, pour melted sealing-wax, or a mixture of two parts of shell-lac and one of Venice turpentine, until it is rather more than half filled, and let it cool gradually. A circular plate of stout tinned iron, or brass, about two inches less in diameter than A, is furnished with a glass handle, B, fixed into its centre. Remove the metallic plate from the cake of resin or sealing-wax A, and excite the latter by friction, with a warm and dry piece of flannel; then place on it the plate C: under these circumstances the negatively electrified cake of resin induces a change in the natural electric state of C, attracting positive fluid into the lower surface, and repelling its negative into the upper. If then C be lifted off by its glass handle, its separated electric will reunite, and it will be found destitute of free electricity. Replace C on A, touch the former with the finger, and its negative electricity, set free by the inductive influence of A, will escape to the earth; then let C be raised, by the handle B, and it will be found to contain positive electricity in a free state, which, on the approach of any conductor, appears in the form of a vivid spark, the plate resuming its naturally unelectrified state. Again, place C on A, touch it with the finger, negative electricity escapes to the earth; lift off C, approach any conductor towards it, and another spark of positive electricity occurs. This process may be repeated an almost indefinite number of times, the cake A losing none of its electricity by the operation, as it acts solely by its inductive influence on the combined electricities actually present in the metallic plate D. Indeed, after being once excited, a spark may be obtained from this instrument, during many weeks, without any fresh excitation, and on this account it has been used as an electrifying machine, and was by its inventor, the celebrated Volta, termed *electroforo perpetuo*. This electrophorus is a most

Fig. 181.



valuable instrument, not only from its affording a beautiful illustration of inductive action, but from its yielding a large supply of electricity.

323. A very useful modification of the electrophorus (322), is made by coating a thin pane of glass on one side with tin-foil to within about two inches of the edge. Placing it with the coated side on the table, excite the other surface by friction with a piece of silk covered with amalgam (275), then carefully lifting the glass by one corner, place it on a badly-conducting surface, as a smooth table or the cover of a book, with the *uncoated side downwards.* Touch the tin-foil with the finger, then carefully elevate the plate by one corner, and a vivid spark will fly from the coating to any conducting body near it; replace the plate, touch it, again elevate it, and a second spark will be produced. An electric jar may be charged, in a few minutes, with an apparatus of this kind only four inches square. This modification of the electrophorus is a most convenient instrument in the laboratory where electricity is required for endiometric purposes, and where the introduction of an electric machine is inconvenient.

324. If a given quantity of free electricity be communicated to a surface exposing sixteen square inches, and a similar quantity be communicated to another of but four square inches of surface, it is obvious that each square inch of the former will contain but one-fourth of that present in every square inch of the latter; hence, although the total quantities of free electricity are similar in each, yet as, in the former, they are spread over four times the surface that they are in the latter, they will be found as much less energetic in producing the phenomena of attraction, and repulsion, induction or light. The electricity present in the smaller surface, is consequently said to be in a state of greater *tension* than in the larger.

325. A rounded surface, as a brass knob, on being held near to, or communicated with an electrified body, allows induction to take place with much less facility than a pointed wire similarly situated, on account of the inductive action being confined to, or exerted from, a smaller surface, causing thereby a greater electric tension on the surface of the point, than of the knob; for this reason, whilst a rounded surface may be approached within an inch of an excited tube (297), without abstracting much of its free electricity, the point of a sharp needle, held at four times that distance, will almost immediately effect the neutralization of the free electricity present in the tube. For this reason, all pieces of apparatus destined to attain free electricity, are terminated by knobs or rounded surfaces; and those intended rapidly to abstract or neutralize this electric matter, are furnished with points. On this circumstance is explained the fact, that an electrified sphere has its electricity equally diffused over its surface, whilst, in the case of an ellipse, the general quantity is found at the termination of its long diameter, and of a cube at the apices of its angles.

326. Having considered some of the principal and simplest phenomena of electricity in a general sense, it becomes necessary to be acquainted with the nature of the exact laws governing them; for a knowledge of these, we are almost entirely indebted to the researches of M. Coulomb, who brought to bear, on this subject, the most accurate experiments with the most refined and valuable resources of mathematical investigation.

Primary Electrostatic Laws.

(A.) Two bodies, similarly electrified, repel each other (299), with a force varying inversely as the squares of their distances.

(B.) Two bodies, differently electrified, attract each other (298) with a force inversely as the squares of their distances.

(C.) Electricity, in its natural and compound state, appears to be diffused equally throughout any given mass of matter, but when decomposed and separated into its component elements, each appears confined to the surface of the substance in which it has been set free, in the form of an exceedingly thin layer, not penetrating sensibly into the substance of the mass (313, 321).

(D.) Bodies, carefully insulated on resinous supports, lose, by exposure to the air, a certain proportion of their free electricity, depending to a great extent upon the moisture present in the atmosphere; the loss, per minute, appearing to bear a ratio to the cubic of the weight of hygrometric moisture in the air.

(E.) Bodies electrified and insulated imperfectly, as on silk, or glass uncovered with resin, lose a portion of their electricity, by its escaping along the imperfectly insulating support, providing the electricity is of considerable tension, for if weak, it is completely insulated; hence the loss of electricity is at first rapid, but quickly decreases.

CHAPTER XII.

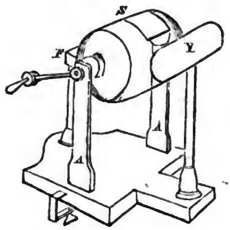
ELECTRICITY. CONSEQUENCES OF INDUCTION.

Electric Machines, 327. *Ozone*, 331. *Use of amalgam*, 333. *Electric spark, or Discharge in the air and in vacuo*, 334. *Electricity of steam*, 335. *Hydro-electric machines*, 336. *Lane's Discharger*, 342. *Heat excited by discharge*, 344. *Attraction and repulsion*, 345. *Currents of air in discharges from points*, 346. *Mechanical effects of discharge*, 347. *Luminous discharge in different media*, 348. *Varieties of electric discharge*, 349.

327. With the exception of the electrophorus (322), we have as yet not had recourse to any instrument furnishing large quantities of free electricity. The first machine constructed for this purpose was contrived by Otto de Guericke, of Magdeburg; it consisted of a globe of sulphur, turned by a winch, and submitted to the friction of the hand. Improvements were very gradually introduced into its construction. First, a globe or cylinder of glass was substituted for the sulphur, and then the silk rubber was used, in lieu of the hand; the last great addition consisted in the adaptation of a metallic conductor, so as to expose a large surface to the inductive influence of the excited glass. The revolving glass electric was used by Hawksbee in 1709, the rubber and conductor being introduced in 1741; Boze, of Wirtemberg, contriving the latter, and Winkler the former; thus rendering the electric machine nearly complete.

328. Two forms of the electrical machine are used in this country, differing from each other in the shape of the revolving electric, which in one is a cylinder, and in the other a plate; each varying in diameter from eight or ten inches to two feet, beyond which size it is inconvenient to use either. The

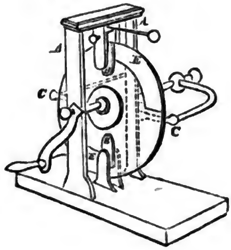
Fig. 182.



best form of cylindric electric machine consists of a cylinder of glass, revolving by means of a winch, between two upright pieces of stout and well-dried wood, A A; this is submitted to the friction of a rubber, formed of an oblong piece of wood, F, about three or four inches shorter than the cylinder, covered with leather, and furnished with a flap of silk, S, extending over nearly half the circumference of the glass. The rubber can be placed at any distance from the cylinder, supported by a strong glass pillar, and connected with a sliding foot of wood, fixed by means of a screw. On the opposite side to the rubber, is a cylinder, Y, of hollow tinned iron, or, what is more convenient in practice, of wood covered with tin foil, and about three or four inches in diameter; this is termed the prime conductor; it is, like the rubber, insulated on a glass leg. The side of the conductor next to the glass cylinder is furnished with a row of pointed pieces of wire, to allow of its more rapidly acquiring an electric state from the revolving inductive glass. This piece of apparatus has a number of holes, of various diameters, bored in it, to permit the insertion of wires of various sizes; the edges of these holes, as well as every other part of the conductor, except the points already mentioned, must be carefully freed from all sharp edges or prominences, which cause a rapid neutralization of electricity (325).

329. The plate machine consists of a circular plate of thick glass, revolving vertically, by means of a winch, between two uprights A A; two pair of rub-

Fig. 183.



bers, formed of slips of elastic wood covered with leather, and furnished with silk flaps, are placed at two equidistant portions, B B, of the plate: their pressure upon the latter may be increased or diminished by means of brass screws. The prime conductor consists of a curved arm of hollow brass, supported horizontally from one of the uprights A; its arms, where they approach the plate at C C, are furnished with points, for the same reason as in the cylindric machine.

Great advantage is gained by causing a row of metallic points, connected with the prime conductor, to be presented to both surfaces of the revolving plate, instead of to one only, as in the usual construction of these machines.

It is very difficult to give an opinion of the comparative merits of these two machines,—for an equal surface of glass, however, the plate appears to be the most powerful; but it has one great inconvenience, viz., the difficulty of obtaining negative electricity from it, in consequence of the uninsulated state of its rubbers.

330. When an electrical machine is required for use, it should be placed within the influence of a good fire, so that its several parts may become dry and warm. The rubber and conductor are to be removed, and the plate or cylinder rubbed with a piece of flannel, dipped in oil, until it becomes quite clean and bright; the layer of oil thus left, being removed with a linen cloth. The rubbers are then to be made quite dry, and their silk flaps wiped clean; a little amalgam made into a soft paste with lard, to be spread over the surface of the cushions of the rubbers, unless there happens to be plenty left on from a previous experiment, in which case the surface is to be cleaned by rubbing it with a piece of rough brown paper, or by scraping it with a knife. The rubber, or rubbers, are to be then applied, and by means of the adjusting screws, made to press with moderate force against the surface of the cylinder or plate. On then turning the winch, and holding the hand towards the revolving glass near the lower surface of the silk flap, the electric discharges will be felt between the hand and glass, like a brisk wind, attended by a crackling sound, and in the dark, by a lambent blue flame. The prime conductor is next placed in such a manner that its points stand about one-eighth of an inch from the glass: on holding the hand towards it, whilst the winch is being turned, vivid sparks, often some inches in length, appear; these are attended by a loud snapping noise, and on striking the hand, produce a pungent pricking sensation, frequently causing a papular eruption on the skin.

331. During the excitation of electricity by the machine, and indeed in other cases in which luminous discharge (312) takes place, a peculiar odor like that of phosphorus is evolved. This odor has been traced by Professor Schönbein, of Bâle, to the formation of a substance termed by him *ozone*, and which he is inclined to regard as a tritoxide of hydrogen (435).

332. The development of free electricity upon the prime conductor is so intimately connected with the theory of induction already developed (315), that the remarks there made will be sufficient to remove all obscurity as to the mode in which it is effected. On turning the glass plate or cylinder, the electricity naturally present in the rubber becomes decomposed, its positive adhering to the surface of the glass, and its negative to the rubber. The positively electric portions of the glass coming, during each revolution, opposite to the points on the conductor, act powerfully by induction upon the electricity naturally present in the latter, decomposing it into the component elements, attracting the negative, which being accumulated in a state of tension (324), at the points of the conductor, dart off towards the cylinder, to meet the positive fluid, and thus reconstitute the neutral compound. The prime conductor is thus left powerfully positive, *not by acquiring electricity from the revolving glass, but by having given up its own negative fluid to the latter.* The

rubber is left in a proportionately negative state, and consequently, after revolving the glass for a few minutes, can develop no more free positive electricity, providing the rubber be (as in the cylindric machine) insulated; on this account, it is necessary to make a communication with the earth, for the purpose of obtaining a sufficient supply of positive electricity to neutralize its negative state. In very dry weather, indeed, the electric machine will frequently not act, until the rubber is connected by a good conductor, not merely to the table on which the machine stands, but to the moist earth, or, what in large towns is more convenient and preferable, with the leaden pipes supplying the house with water.

333. Much discrepancy of opinion has existed concerning the modus agendi of the amalgam applied to the rubber; it certainly acts very powerfully in increasing the excitation of electricity. The best combination for this purpose consists of two parts of zinc and one of tin, melted together, and added to six parts of mercury, previously heated in a crucible: the mixture being stirred until cold, is readily reduced to a fine powder, which requires merely to be formed into a paste with lard, to be ready for use. It has been, with good reason, supposed that the oxydation of the amalgam, by the friction employed, aids at least the increased excitation; for amalgams of gold, and other difficultly oxydizable metals, do not appear to increase the development of electricity. In accordance with this view, Dr. Wollaston found that an electric machine, when worked in an atmosphere of carbonic acid, gave no signs of free electricity.

The accuracy of this statement has, however, been questioned by later observers. One mode in which the amalgam acts is certainly by affording a soft cushion of good conducting matter, which thus affords an excellent surface for inducing the decomposition of the neutral electricity on the revolving glass.

Instead of an amalgam, the deutosulphuret of tin, or aurum musivum, as it is often called, may be rubbed upon the cushions of the machine, and with similar results. This latter substance acts probably like the amalgam, by undergoing oxydation, as by friction it absorbs oxygen, and is partially converted into bisulphate of tin. In a similar manner also iron pyrites, by friction, is partly converted into sulphate of iron. The chemical influence of friction, indeed, is more energetic than is usually supposed; even siliceous minerals, as mesotype, basalt, and feldspar, become, according to Becquerel, partly decomposed, giving up, when long triturated in a mortar, a portion of their alkali in a free state.

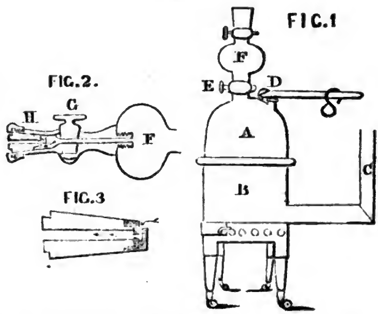
334. When the plate or cylinder of the machine is turned, the rubber communicating to the earth by a metallic chain, if a brass knob or a knuckle be held towards the prime conductor, a vivid spark darts between them. This spark is usually spoken of as a positive spark, as though it consisted of positive electricity passing from the conductor towards the knob, or knuckle. This, however, is an erroneous expression; for as the prime conductor is positively electrified, it induces (315) an oppositely or negatively electric state in any conducting substance held near it; and when this state has amounted to one of sufficient tension, the negative electricity combines with the positive of the prime conductor; thus restores it to its natural unelectrificial state. The neutralization, or *discharge* of the electric state of the conductor, is attended by a sharp snapping sound, and a flash of light, constituting the *electric spark;* consequently, whenever an electric spark is seen, it is not to be regarded as arising from the mere passage of free electricity, but of the union of the two electric fluids, and consequent discharge of the electrified body. The sparks of *positive* electricity said to pass from the excited tube (312), or cover of the electrophorus (322), are of the same kind. From these facts also, we adduce

the necessary consequence that all cases of electric discharge must be preceded by induction.

When the prime conductor is connected with the earth, and the *rubber* of the machine insulated, sparks are seen on approaching the hand, or other conductor, towards it; these are termed sparks of *negative* electricity, but as erroneously as in the case of sparks from the prime conductor; as they arise from the discharge of free electricity in the rubber, by its union with the induced positive electricity in the nearest conducting body.

335. Some few years ago, a workman on the Newcastle and Carlisle railway observed an electric spark to issue from the boiler of a steam engine on the approach of his hand. This curious phenomenon induced Mr. Armstrong to investigate the subject, and his researches, with the later ones of Dr. Faraday, have put in our hands a mode of exciting electricity to an almost indefinite extent. It appears that whenever a current of steam escapes from a boiler with sufficient violence to carry off mechanically particles of water, it will in its course through a proper escape-pipe excite by the friction of the water against the sides of the pipe an enormous quantity of electricity. Upon this principle is founded the construction of the hydro-electric machine of Mr. Armstrong.

Fig. 184.



This consists of a spherical boiler of wrought iron, at least eighteen or twenty inches in diameter, of sufficient strength to bear a pressure of sixty or seventy pounds on the inch. This boiler, A, rests on a small furnace of sheet-iron, B, and furnished with a bent chimney, C. The whole is carefully supported on four stout legs of glass. The boiler is provided with a proper safety-valve, D. From its upper part, a tube an inch or more in diameter rises, furnished with a stop-cock at E. To the end of this tube is fixed a spherical vessel of brass, F, about six inches in diameter. From the upper part of this a tube furnished with a stop-cock and a peculiar jet is fastened. The construction of the latter is shown at Fig. 2, in which the whole is seen in section, F being the spherical vessel, G the stop cock furnished with a stout brass cap, H, into which is firmly screwed the jet, Fig. 3. This represents the section of a conical plug of box-wood, terminated by a brass mouth-piece. The shaded parts represented the metallic portion.

Having filled the boiler about half full of water, and placed burning charcoal in the furnace, in a short time the water will boil, and after the air has been first expelled, the stop-cock E should be closed, and the globe F and its

escape pipe screwed on. When the quantity of steam generated is equal to a pressure of fifty or sixty pounds to the inch, open the stop-cocks E and G, some of the effluent steam will be condensed in F, and the particles of water violently driven forward with the vapor through the wooden mouth piece of the jet. The boiler will be found powerfully negative, and on approaching a brass ball to it, long and vivid sparks will dart off. The steam leaving the escape-pipe, will be positively electrified, and it is necessary to obtain an efficient discharge of its electricity, for which purpose a coil of thick copper wire connected with the earth may be so placed, a few inches from the escape-pipe, that the current of steam may traverse it.

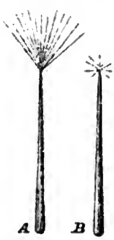
337. With such an hydro-electric machine, so large a quantity of electricity may be obtained as to enable it to replace with advantage the ordinary electric machines. The only objection to its general adoption is, that unless the boiler be sufficiently large, the steam quickly assumes too high a state of tension, and an explosion may not be impossible. Such an accident did occur at Guy's Hospital, even with all the care employed by Dr. Gull, my talented successor in the chair of Natural Philosophy at that institution.

338. It is remarkable, that so long as the globe F contains merely a little pure water condensed from the steam, the excitation of electricity is abundant; but if a little sulphuric acid or common salt is placed in, all generation of electricity ceases, apparently in consequence of the water being rendered too good a conductor, and thus allowing of the restoration of electric equilibrium as soon as it is disturbed by friction. If a little oil be dropped in, the excitation of electricity continues, but is changed in character, the boiler positive, and the steam negative.

There can scarcely be a question of the accuracy of the opinion of Dr. Faraday,* that friction is really the exciting cause of electricity in this machine; for if the steam be allowed to escape even in torrents, and under high pressure from the opening of the safety-valve, no electric excitation occurs. Hence the necessity of so arranging the opening of the escape-pipe, as to oppose some opposition to the passage of the steam.

339. If a pointed wire be held towards the insulated rubber of an electric machine in action, it will by induction become highly positive; the electric tension at the point soon becomes so high as to produce discharge through the dielectric air, in the form of a brush or pencil of rays, as at A. When, on the other hand, a similar point be held towards the positive prime conductor, it acquires a high state of negative tension, and luminous discharge occurs, not in the form of a brush or pencil; but the end of the wire becomes illuminated with a minute but brilliant star of light. By using similar wires, we can in every instance discover the electric state of a conductor by the character of the luminous discharge occurring at the points of a wire held towards it.

Fig. 185.



340. If the conductor, or rubber of the electric machine, be connected with each other, or with the earth, by means of a continuous conductor, as a piece of wire, the electric discharge will take place along it invisibly, unless the machine be extremely energetic, in which case the wire will appear surrounded with a lambent flame. But if the conductor be interrupted, then vivid sparks will appear at each rupture of continuity, arising from inductive action and consequent discharge taking place at every one of these spots.

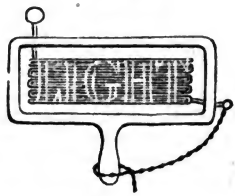
Exp. (A.) Connect the prime conductor and rubber with each other, by

* Phil. Trans., 1843, p. 17.

means of a brass chain; on working the machine, vivid sparks will appear at every link.

Exp. (B.) On a plate of glass, paste some strips of foil, having portions cut out, so that the spaces represent letters. On communicating the first piece of foil with the conductor, and the last with the ground, the letters will appear in characters of fire, in consequence of luminous discharges in the form of a spark occurring at each division of the foil.

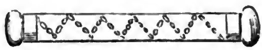
Fig. 186.



Exp. (C.) Draw, on a pane of glass, a serpentine line with varnish, and place on it, before it dries, metallic spangles, about one-tenth of an inch apart; on connecting the first of the series with the machine, and the last with the ground, a serpentine line of fire will be represented.

Exp. (D.) If, in a similar manner, the spangles are placed on a glass tube in a spiral direction, a fine spiral line of sparks will be produced.

Fig. 187.



341. Induction, and consequent discharge, take place through a greater space in an air-pump vacuum than under ordinary atmospheric pressures, a circumstance arising from the resisting dielectric medium being diminished in density. This led to the error of considering a vacuum as a conductor of electricity, which is not the case, polarization of the particles of rarefied air, and consequent discharge being affected through it readily, only if the two surfaces be sufficiently near to permit induction to take place; otherwise, electrified bodies can be as well insulated in an air-pump vacuum as in common air.

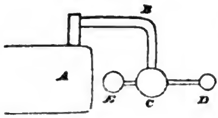
Exp. (A.) A glass tube, two feet in length A, is furnished at either end with a brass ball projecting into its interior, and carefully exhausted of its air, by means of a good air-pump. On connecting its upper end B, with the prime conductor of a machine in action, and its lower end C with the earth; B becomes positive, and induces a contrary state on the ball at C, induction taking place with facility in consequence of the atmospheric pressure being removed, and is followed by a discharge of the two electricities in the form of a beautiful blue light, filling the whole tube, and closely resembling the aurora borealis. This luminous discharge undergoes some very interesting changes when the state of rarefaction of the air included in the tube is filled with a purplish lambent flame. If a little air be then admitted, the continuous column of light is replaced by distinct flames repeated several times in a second, and darting from one ball to the other. And if more air be allowed to enter, the discharge takes place in beautiful zig-zag lines of brilliant light, like flashes of lightning, occurring however at considerable intervals.

Fig. 188.

342. In all these experiments (340), it is better to allow the electricity, before passing through the tinfoil, chain, or luminous conductor (341), to acquire some degree of tension; this is conveniently effected by means of an instrument called Lane's *electrometer*, or more properly, *discharger*. This apparatus

consists of a curved arm of varnished glass B, fixed by a brass leg into the prime conductor A, and terminating in a ball C, through which passes a rod furnished with two brass knobs, capable of being placed at any distance from the conductor. If any of the above-described pieces of apparatus be connected with the ball D, electric discharges will take place through them, as soon as the electricity has acquired a sufficient state of tension to effect a discharge between A and E.

Fig 189.



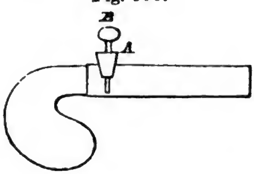
343. Every conducting substance, insulated and connected with the prime conductor, or rubber, may be considered as part of them, as far as their electric state is concerned: thus if a man standing on a stool furnished with insulating glass legs touch the prime conductor, he virtually becomes part of it, being similarly electrified, and all the phenomena proper to the prime conductor may be observed at any part of his surface.

344. The electric spark, or more properly *discharge*, does not impart to the finger a sensation of sensible heat, although it is capable of exciting sufficient caloric (367) to produce the combustion of inflammable substances.

Exp. (A.) Connect a shallow metallic cup with the prime conductor, and pour ether into it; on holding the finger or a knob of brass over it, the electric discharge taking place through it will evolve sufficient heat to inflame the ether.

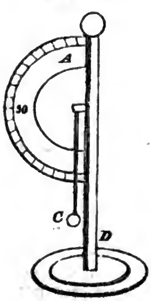
Exp. (B.) Put into a bottle granulated zinc, and some dilute sulphuric acid; fix in its neck a cork furnished with a tube, terminating in a small aperture: hydrogen gas will issue from it, and on holding it close to the conductor, and by means of a brass knob drawing a spark through the stream of gas, it will burst into flame.

Fig. 190.



Exp. (C.) A brass tube, mounted on a stock like a pistol barrel, is furnished with a glass or ivory tube, screwed into A. Through this passes a brass wire, passing into the interior of the barrel, but not touching it; the brass tube is then filled with an explosive mixture, by holding it for a few seconds over the mouth of a bottle containing the ingredients for the production of hydrogen gas. On closing the mouth quickly with a cork, the charge is retained, and on approaching the knob B to the prime conductor, a spark is produced in the interior of the barrel, the gases are exploded, and the cork driven out with considerable violence, attended with a loud report: this apparatus is termed Volta's electric pistol, from the name of its inventor.

Fig. 191.



345. The phenomena of attraction and repulsion, (298,) are exceedingly well illustrated by means of the electricity excited by the electric machine, and various toys have been contrived for their exhibition.

Exp. (A.) Fix into one of the holes of the prime conductor the instrument called Henley's electrometer, consisting of a graduated semicircle of ivory A, fixed to a rod of wood D. From the centre of A depends a light index, terminating in a pith-ball C, and readily moving on a pin. On working the machine, the electrometer becomes, like the conductor, positively electrified; the

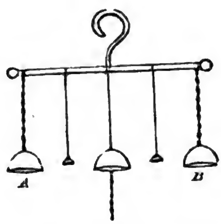
pith ball C consequently, becomes repelled by the stem D and leaves it raising the index to 90°, if the action of the machine be sufficiently strong.

Exp. (B.) Place in one of the holes in the prime conductor, the stem of an artificial feather, formed of fibres of finely-spun grass. On revolving the cylinder, the fibres becoming similarly electrified, repel each other in an extremely beautiful manner.

Exp. (C.) Suspend from a brass rod, (Fig. 192,) inserted into the conductor of the machine, a plate of copper, about four inches in diameter, and about two inches beneath it, place a second of rather larger size; on electrifying the conductor, the positive electricity of the upper, renders the lower plate negative by induction, and discharge would ensue, if they were not too far apart. On the lower, place some figures of pith of elder or paper, and on turning the machine, they will begin to dance between the plates, being alternately attracted and repelled by each other.

Fig. 192.

Fig. 193.



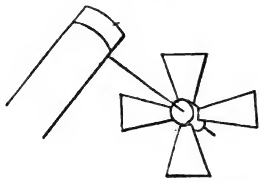
Exp. (D.) Suspend, from a rod on the conductor, the apparatus well known as the electric bells. The two outer bells AB, (Fig. 193,) are suspended by brass chains, whilst the central, with the two clappers, hang ftom silken threads; the middle bell is connected to the earth by a wire or chain: on turning the cylinder, the bells A and B become positively electrified, and by induction, the central one becomes negative; luminous discharge taking place between them, if the electricity be in too high a state of tension. But if the cylinder be slowly revolved, the little brass clappers will become alternately attracted and repelled by the outermost and inner bells, producing a constant ringing so long as the machine is worked.

Exp. (E.) Fix to the conductor a dozen threads,—each about eight inches long, tied at both ends; on turning the machine, the threads becoming similarly electrified will repel each other, and as they are fixed at top and bottom, their centres will repel each other, and separating, the threads will represent a skeleton spheroid so long as the machine is turned.

346. If a pointed wire be fixed to the prime conductor, a discharge takes place silently from it, in the form of a luminous pencil of rays, on working the machine; this is accompanied by a brisk current of air, very sensible to the finger, when held near the point.

Exp. (A.) Fix four vanes of pasteboard in a circular piece of cork furnished with a steel needle for an axle; suspend this from one of the poles of a bar magnet, and on holding it towards the point of a wire fixed in the conductor, so that the current of air excited by the discharge from it may strike the vanes, the little apparatus will begin to revolve with great rapidity.

Fig. 194.



The current of air thus set in motion, by discharges from pointed wires, is sufficient to react upon them, and cause them to move in an opposite directian to the current, provided they be fixed on an axis.

Exp. (B.) Place the cap of the electrical fly, furnished with four pointed wires bent near their terminations at right angles, on a pivot fixed in one of the holes of the prime conductor. On turning the winch, the wire will rapidly revolve in a direction opposed to the points, as shown by the arrows, exhibiting in the dark a complete circle of light.

Fig. 195.

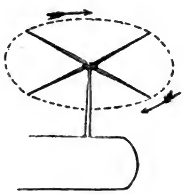


Fig. 196.

347. The mechanical force of electric discharge is very considerable, providing its effects be concentrated in one particular spot.

Fill a phial with oil, or other non-conducting fluid, pass through the cork a copper wire bent near its lower end at right angles, so that its point may press against the inside of the glass, and suspend it by the upper end of the wire from the prime conductor. The point of the wire in the phial will assume a high state of positive electric tension (324). Then bring towards it a brass knob, or a knuckle of the hand, induction and subsequent discharge will take place through the sides of the glass, which will become perforated with a round hole.

348. The electric spark (discharge), passing through media differing from atmospheric air, varies considerably in tint. Thus, in rarefied air, its light is blue and less vivid than when under ordinary atmospheric pressure. Dr. Faraday found that, in nitrogen, it was very brilliant, bluish, and sonorous; in oxygen, less brilliant and white; in hydrogen, crimson, and accompanied by little or no sound; in carbonic acid its tint was rather more green than in air; in coal-gas it was green or red, sometimes both, with frequent interruptions by black spots; and in hydrochloric acid gas, white, without any of the dark spots so frequently present in the case of the other gases. Occasionally,

the spark appears interrupted in its centre by a non-luminous spot, owing to discharge taking place at that point in a more diffused manner than nearer the inducting surfaces. In common air, the luminous electric discharge or spark, becomes modified in tint according to the surface at which it takes place; thus, from a large brass ball, it is white and brilliantly luminous, whilst, as we diminish the size of the ball, it becomes bluer and more scattered, assuming the form of a brush, which itself depends upon a series of intermitting discharges taking place with considerable rapidity. From the surface of ivory, the discharge is crimson colored; from silvered leather it is green; from powdered charcoal, yellow; and purplish, when taking place on the surface of most imperfect conductors of electricity. The light of the electric discharge is capable of undergoing decomposition by a glass prism, and polarization by reflection or absorption, like ordinary light.

349. Several varieties of electric discharges have been pointed out and are readily distinguished by their attendant phenomena.

(A.) *Conductive discharge.*—This takes place when bodies differently electrified are connected by means of a good conductor. It is unaccompanied necessarily by any chemical action or displacement of particles.

(B.) *Disruptive discharge.*—Under this term is included all the varieties of electric discharge, accompanied by light, from the faint lambent gleam at the extremity of a wire to the vivid flames and sparks, accompanying the restoration of electric equilibrium between good conductors. In all cases of this discharge an actual displacement of particles through which it occurs, takes place. We have a good example of it in the frequent rupture of electric jars by spontaneous disharge taking place through them; the perforation of a glass bottle full of oil (347), is also a case of this kind.

(C.) *Convective discharge.*—A form of discharge in which, under the influence of electric currents, ponderable matter is set in motion. Thus, the aërial currents from points (346) are examples of the convective discharge. Another series of cases in which ponderable matter is transferred by the electric current, is found in almost all instances of discharge between metallic surfaces or charcoal points, minute portions of the material of which the conductor is composed, being conveyed from one surface to the other, so as to cover it with a superficial coating of the material of which a ball is composed. The direction of the transfer in these cases of convective discharge being in the direction of the positive current.

CHAPTER XIII.

ELECTRICITY. CONSEQUENCES OF INDUCTION.

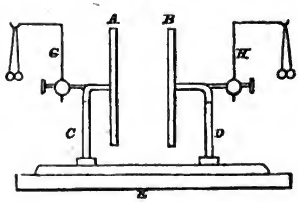
Disguised electricity, 350. *Charge and discharge of coated dielectrics*, 351. *Charge penetrates substance of dielectrics*, 353. *Leyden jar*, 355. *Insulated jars cannot be charged*, 358. *Battery*, 359. *Residual charge*, 361. *Velocity of electricity*, 362. *Charge does not reside in the coating*, 363. *Discharger*, 364. *Experiments with charged jars*, 365—*with battery*, 366. *Heating effects*, 367. *Leyden Vacuum*, 369. *Lichtenberg's figures*, 370. *Intensity and quantity*, 371. *Unit jars*, 372. *Condenser*, 373. *Condensing electrometer*, 374. *Returning shock*, 376. *Unipolar bodies*, 377. *Conversion of non-conductors into conductors by heat*, 378.

350. When two insulated conducting bodies are differently electrified, and approached towards each other, so as to be within the influence of their mutual attraction (326, B,) but not sufficiently near to permit of luminous discharge, no signs of electricity are communicated by either to a pith-ball electrometer connected with them, until the bodies are separated to a considerable distance from each other. The electric fluids are thus said to become *disguised*, or *paralyzed*, by their mutual attractive action.

Exp. (A.) Let two plates of tinned iron, AB, a foot in diameter, be insulated on varnished glass legs, CD, fixed into pieces of wood moving in a groove in the board E. To the backs of each of these plates is soldered a brass wire, furnished with a binding screw, grasping wires, GH, from each of which is suspended a pith-ball electrometer.

Separate A and B from each other, and touch one with an excited piece of glass, the other with excited resin, the pith-balls connected with each plate

Fig. 197.



will diverge, one with negative, the other with positive electricity. Carefully approximate the plates, and as their mutual distance diminishes, the pith-balls will gradually collapse, until A and B are very near to each other, when they will appear totally unelectrified.

Exp. (B.) The apparatus being in this state, gradually separate A and B, and, in proportion as this is done, the pith-balls will diverge as before, proving that the electric states of the plates had not been *destroyed* during the previous experiment.

351. These phenomena depend upon a very simple cause, the attraction of the electricity in A being sufficient to draw all that of the opposite kind in B,

from the wire H, into that part of the plate opposite it; whilst the electricity in B acts in a similar manner on that in A, polarizing the particles of the intervening dielectric air. Thus, by their mutual attraction the two fluids are collected into those surfaces of the plates nearest each other, and being by their attractive influence, retained there, become incapable of action on the electrometer: on separating A and B, this attractive influence decreases (326), and the electric fluids being diffused over the surfaces of A and B, act upon the electrometers connected with them. The two electric fluids cannot unite by luminous discharge, until A and B are very close to each other, and then on making the communication with a curved wire, they unite, and mutually neutralize each other, producing a true disruptive discharge (349).

Next, remove all free electricity from both A and B, bring them within one-sixth of an inch of each other, and touch A with an excited glass-tube; it thus becoming positively electrified, acts by induction on the electricity in B, attracting its negative and repelling its positive fluid, which, running up the wire H, reaches the pith-balls and causes them to diverge. Touch B with the finger, and the positive electricity thus separated by induction, will escape, leaving B negative; its electrometer cannot diverge, because its negative fluid is retained in the surface opposed to A (317). Separate A and B, both electrometers will indicate free electricity of an opposite kind in each; again approach them and the pith-balls will as before collapse. Then connect A and B, by a curved wire, and the two fluids will rush together and unite, producing a luminous discharge. In this experiment we have the second plate B, becoming negatively electrified through air as a dielectric, and this plate of air is said to be *charged*, its particles, lying between A and B, becoming polarized, and arranged as required by the theory of induction; the latter force being necessarily and solely exerted between contiguous particles (319).

The plate of air thus becoming charged, may be discharged and reduced to its primitively unelectrified state, in two modes; first, by gradual and silent, secondly, by explosion and sudden discharge. The conditions for producing the first, are fulfilled by merely leaving the instrument exposed to the air for a sufficient space of time, gradually the electricities in the two plates combine, and the separating dielectric air is necessarily discharged. For the second mode, all that is necessary is to connect the plates A and B by means of a curved wire or other conductor, the free electricities then combine, suddenly producing a luminous discharge.

352. Any other dielectric may be submitted for air in these experiments, and if a plate of glass or resin be used, the electricities accumulated in its two surfaces may be increased to a very considerable degree of tension (324).

Exp. (A.) Place a large pane of glass, about fourteen inches square, between the two plates of the apparatus (250), and bring A and B so near to each other as to tightly grasp the pane. Connect A with the prime conductor of the electric machine, and work the latter so as to render the plate powerfully positive: this will act by induction through the pane of glass, on the electricity naturally present in B, as before (351), repelling its positive, which, on approaching the hand to the back of B, will produce a series of sparks, or discharges (334). After a certain time these will cease; then remove the wire connecting A to the prime conductor, and leave it insulated; the plate A will then be charged with positive, and B with negative electricity, both in a state of high tension. Connect the two plates by means of a curved wire, and *disruptive discharge*, arising from the union of the electric fluids, results, attended with a vivid flash of light and a loud snap. If, instead of using a curved wire, the plates be connected by the fingers of both hands, the same discharge ensues, accompanied by an exceedingly disagreeable and

painful sensation, extending across the arms and chest of the experimenter, well known as the electric shock.

Exp. (B.) Instead of placing a pane of glass between the two metallic plates, coat it on each side with a piece of tin-foil, leaving about one inch and a half all round uncovered. On connecting one piece of tin-foil with the conductor of the machine, and the other with the earth, the glass dielectric will become charged as before, that side connected with the conductor acquiring a powerfully positive, and the other an equally energetic negative charge.

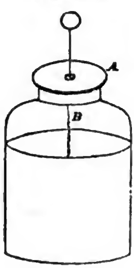
353. The *charge*, thus communicated to the plate of glass, penetrates its substance to a certain distance, as was first pointed out by Mr. Henley.

Exp. (A.) Coat two thin pieces of window-glass on one side only with a piece of tin-foil, considerably smaller than the glasses; place them together, with their uncoated sides in contact. Charge this double plate as before, and then attempt to separate them, they will be found to adhere very tightly together; on pulling them assunder, the naked side of that plate which had been connected with the conductor will be found positively, and that of the other plate negatively electrified.

This may be still more readily shown, in the manner proposed by Dr. Faraday, by charging in the same manner two plates of spermaceti covered on one side with tin-foil. The imperfectly insulating character of this substance enables us to detect this penetration of the charge more readily than when glass plates are used. At the instant the *discharge* takes place, the two electricities accumulate in a state of high tension on the coated surfaces of the glass, pass from a state of rest into one of rapid motion, constituting the *electric current*. There are indeed two such currents, one of positive the other of negative electricity, traversing the conductor joining the two coatings in opposite directions; these currents are of but momentary direction and cease the instant the electric equilibrium of the dielectric is restored.

354. Induction, and subsequent charge, do not appear to be materially modified by the figure of the glass, its thickness only influencing these actions, *cæteris paribus*, the thinner the glass the more powerful charge will it hold. As the plate is a very inconvenient piece of apparatus, on account of its being readily injured, glass jars or bottles coated with some conductor, are almost universally substituted for it. This, indeed, was the first arrangement used, forming the celebrated electric or Leyden phial, so called from the place of its discovery, by Cuneus or Muschenbroek, in 1700. Green or white glass answers almost equally well for the construction of electric jars; wide-mouthed glass jars are very convenient, but on account of their expense, common wine-bottles may be very conveniently substituted, provided they are free from air-bubbles, and specks of unvitrified matter.

Fig. 198.



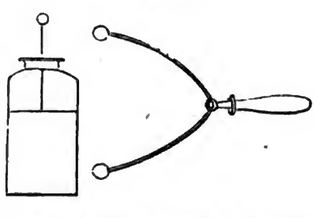
355. The ordinary Leyden phial, or jar, consists of a glass bottle of any convenient size, coated internally and externally with tin-foil to about three inches from its mouth. The latter is closed by a dry and varnished cork, or wooden disc A. A stout brass wire, furnished with a ball of the same metal, passes through the cover A, and has several thin pieces of wire, or a chain fixed to its end B, so as to touch the inside coating in several places. The knob thus corresponds to the internal coating. When narrow-mouthed jars or bottles, as the common sixteen ounce phials of white glass (which from their thinness form excellent electric jars) are used, it is better to coat them internally with brass filings, instead of tin-foil, on account of the difficulty of applying the latter to their interior. For this purpose some thin glue should be poured into

them, and the bottle turned slowly round, until its inner surface is covered to about three inches from the mouth. Brass filings are then put in, and the bottle well shaken, so that they may be diffused equally over its surface; on inverting it, those which are in excess will fall out, and the bottle will be left coated internally sufficiently well for its intended purposes. Some jars should always be provided with hooks, instead of knobs, as it is requisite frequently to suspend them to the prime conductor. To prevent the too rapid deposition of moisture on the uncoated part of the glass, it is a good plan to varnish the jar above the external coating, with a solution of shellac in alcohol, or with the common spirit-varnish of the shops: taking care to warm the jars before, and after its application.

356. If the knob of a jar (355) be held about half an inch from the prime conductor, whilst its outside communicates with the earth, a rapid succession of sparks will take plece between the knob and conductor, which will continue for some time, and then cease. The jar will then be *charged*, its inside containing positive, and its outside coating negative, electricity; their union being prevented by the interposed glass, unless the tension of the electricity be considerable, in which case, discharge often ensues through the glass, which then becomes perforated, and the jar rendered useless, or else by passing over the surface of the uncoated shoulder of the bottle in the form of a bluish lambent brush of flame, constituting the spontaneous discharge. If the electric tension be not sufficient to produce these phenomena, and the bottle be set aside, its electricity becomes gradually neutralized by the conducting action of the surrounding atmosphere.

357. When an electric jar is charged (355), its discharge may be effected by connecting its outside coating with the knob, by means of a thick curved wire, which is generally furnished with a brass ball at each end. This instrument or discharging-rod is usually fixed to a glass handle, and a cradle-joint, like a pair of compasses, so as to allow the metallic arms to be placed at different distances from each other. The jar may be also discharged by

Fig. 199.



grasping its external coating with one hand, and touching the knob with the other, in which case the person who performs the experiment, experiences the peculiar and painful sensation, termed "the shock" in his arms, and if the jars be large, through his shoulders and chest. A charged jar whose outside contains negative and inside positive electricity, is said to be positively electrified; and to be negatively electrified, when the electricity of its internal coating is of that kind.

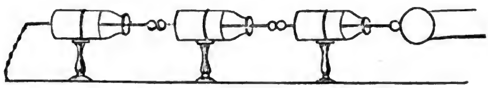
358. In accordance with the conditions of the induction and disguise of electricity (358), it is obvious that an insulated jar cannot be charged (350).

Exp. (A.) Place a jar on an insulating support, as a stool with glass legs, with its knob in contact with the prime conductor; on working the machine for some time, and examining the jar, it will be found to be almost destitute of any electric charge. For on connecting its outside and inside coating, by

means of the dischargiug rod (357), no discharge takes place, a faint spark only appearing between the knob of the discharging rod and the jar.

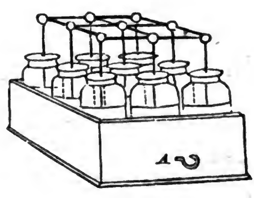
Exp. (B.) Place the jar in the same position, and while the machine is in action, approach he finger to the outside coating, vivid sparks will pass towards it, arising from the positive electricity belonging to the outside of the jar, uniting with the negative in the finger. After a certain time these sparks will cease, and on approaching the discharging rod to the jar, the flash of light and loud snap that ensue, prove that the jar has received a considerable charge. If the knob of a second jar be substituted for the finger, it will become charged by the electricity, repelled from the outside of the first jar; this mode of charging is termed, by the French, "charger en cascade." And in this manner a series of jars can be readily charged, representing a polar arrangement, in which the knobs of the jars are all positive and the outside coatings all negative.

Fig. 200.



359. The *charge* of an electric jar varies, *cæteris paribus*, with the extent of coated surface; and on this account, very large jars have been constructed. These, however, have several inconveniences, and among them may be mentioned, the necessary thickness of the glass when the jars are very large, preventing induction to any great intensity taking place through them. On this account, several small jars coated in the usual manner (355), are placed in a box lined with tin-foil, or other good conductor, so as to connect their outsides, whilst their knobs, and consequently their insides, are connected by brass rods. The whole constituting the *electric battery*. As the interior of all

Fig. 201.



the jars communicate, they may be charged as a single jar (556), their exteriors being connected with the earth. A hook, A, is fixed in the side of the box in contact with the metallic lining, so as to allow readily communicating chains or wires with the outside of the jars.

360. In charging a battery, its interior is connected by means of a wire or chain with the prime conductor, and its exterior connected with the earth; and for the purpose of tracing the progress of the charge, the quadrant electrometer (345, A) is fixed in one of the holes of the prime conductor. On turning the machine, the positive electricity accumulating in the inside of the battery becomes disguised (350), by the inductive action of the outside coating, and consequently does not act on the electrometer (351). But in pro-

portion as the electricity ceases to be retained by this action and accumulates in the conductor, it acts on the electrometer and raises its index, which, when the battery has attained its utmost charge, seldom rises above 40° or 50°: as the tension of a battery charge never equals that of a single jar, probably on account of the larger surface exposed to inductive action. The battery may be discharged like a single jar, by connecting its outside and inside, by means of a discharging rod (357), or a chain. Great care should be taken in this operation to avoid passing any of the charge through the body, as the shock from a powerful battery might be attended with serious consequences.

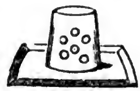
361. After a large jar or battery has been discharged, its two surfaces should be left connected for some time, as a *residual charge*, arising from the return of the electricity which had penetrated the substance of the dielectric (353) to the coatings, often takes place, and may give a severe shock to a person touching the battery without this precaution. According to Reiss, the quantity of free electricity neutralized by the first discharge, amounts to $\frac{11}{13}$ only of the entire charge, $\frac{2}{13}$ being left for the residual charge.

362. When the two surfaces of a charged jar are connected by means of the discharging rod (557), or a long metallic wire, the two electric fluids rush together and unite with an enormous velocity. In fact, even with the largest circuit yet employed, their union appears to be absolutely instantaneous. From a series of very beautiful experiments performed by Professor Wheatstone,* it appears probable that the electric fluid, in passing through a conducting wire from one side of a charged jar to the other, rush through the conductor with a velocity equal to about 576,000 miles in a second of time.

363. From the above remarks it is obvious that the coatings are by no means essential to an electric jar; they act only as surfaces limiting the inductive action, the *charge* itself residing, as has been already shown, in the glass. This may be further proved, by providing a wide mouthed glass jar with movable coatings; charging it (356), and removing the coatings, these will be found unelectrified, and on replacing them by another pair, the jar may be discharged, the flash accompanying which act, will be found scarcely less than that of a jar whose original coatings have been retained.

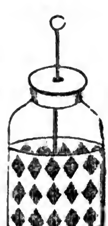
A jar may also be charged without metallic coatings; to show this, let a glass tumbler be grasped by the hand, and its mouth held over a pointed wire, fixed on the prime conductor of a machine in action; it will become charged, and on fitting a pair of coatings to it, it may be discharged like a common jar. If, instead of discharging it, it be inverted on a table over some light pith-balls, these will be attracted by its internal surface in a very curious manner, and the discharge will become gradually effected.

Fig. 202.



The coating, as might be from these facts expected, needs not to be continuous; it may consist of a number of separate pieces of tin-foil fixed at a small distance from each other. Jars thus coated, are termed *diamond jars*, from the brilliant scintillations appearing on their surfaces when they are charged and discharged.

Fig. 203.

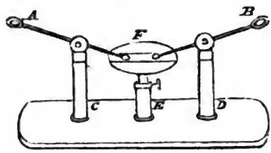


364. When the union of the two electric fluids, necessary for the discharge of a jar, is effected by various conductors connecting the two surfaces, the charge is said to pass through them, and very important and interesting mechanical and chemical effects are thus produced. For the purpose of passing the charge through different bodies, a very convenient piece of apparatus, called the *universal discharger*, is em-

* Phil. Transactions, 1834, p. 591.

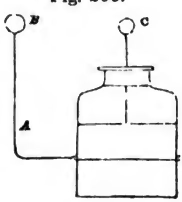
ployed; this consists of two brass wires, A B, terminating in points, to which balls are screwed, and furnished with a ball and socket or cradle joint, so that they are movable in any direction on the tops of the glass supports C D. A hollow wooden support, E, is fixed midway between them; into this is screwed a small wooden table having a slip of ivory inlaid on its surface, on which any substance to be subjected to the action of the current is placed. A small press is sometimes placed in E, instead of the table F, for the purpose of submitting bodies to the action of the charge whilst under pressure.

Fig. 204.



365. The following experiments, requiring for their performance a charged jar, exposing about a square foot of coated surface, will illustrate exceedingly well the general properties of accumulated electricity.

Fig. 205.



(A.) Fix to the outside coating of a jar a curved wire, A, terminated by a metallic ball B and rising to the same height as the knob of the jar, *c*. Charge the latter, and hang by a silken thread midway between B and C, a cork ball, suspended by a piece of silk thread. The ball will become immediately attracted by C, then repelled to B, again attracted, and so on, continuing this active motion until the jar is discharged.

(B.) Insulate a charged electric jar on a support with a glass leg, and connect the electric bells (345) to its knob. They will remain at rest, until the outside of the jar is placed in connection either with the ground, or with the chain connected to the middle bell, when the clappers will be set in active motion, and will continue striking the bells until the jar is discharged.

(C.) Place some gunpowder on the table of the universal discharger (364), unscrew the knobs from the wires A B, and immerse their points in the powder, at about half an inch from each other. Connect the outside of the charged jar with the rod A, by means of a chain, and touch B with its knob, the *charge* will pass through the powder, and scatter it in all directions without inflaming it. An effect probably arising from the enormous velocity (362) with which the electric discharge occurs, not allowing sufficient time to produce the effects of combustion.

(D.) Place some more gunpowder on the table of the discharger, and arrange the apparatus as before; connect the outside of a charged jar with A, by means of a piece of thick *string soaked in water*, instead of a chain; touch B with the knob of the jar, and the gunpowder will be instantly inflamed. The action of the wet string appears to favor the combustion, by impeding that velocity with which the electricity traverses the powder, and thus allowing time for the production of its caloric effects.

(E.) Tie some tow loosely over one of the balls of the discharging rod

(357), and dip it in powdered resin; place the naked ball in contact with the outside of a charged jar, and bring the other in contact with the knob. Discharge will take place, and the resin will burst into flame; the combustion being favored by the badly-conducting nature of the tow and resin.

(F.) Place between the knobs of the universal discharger (364), a thick and dry card, and discharge a jar through it. A perforation will be produced, the card at that point being *burred* outwards in both directions, as though the force producing the perforation had emanated from the centre of the thickness of the card in two opposite directions.

(G.) Color a card with vermilion, unscrew the balls from the universal discharger, and place the points on opposite sides of the card, one about half an inch above the other; and discharge a jar through them. The card will be always perforated at the point opposite to the wire, connected with the negative side of the jar. A black line of reduced mercury will be found extending from the point where the positive wire touches the card, to the place of perforation. This curious effect is attributed to the great facility with which positive electricity passes through air, as compared to negative. If this experiment be repeated *in vacuo*, the perforation always takes place at a point *intermediate* between the two wires.

366. When electricity is accumulated in large jars, or, still better, in a series of jars constituting the battery, we are capable of producing results which simulate the effects of lightning; and may be considered as bearing the same relation to the area in which they are exhibited, as the former does to the great theatre of nature, in which its no less grand than awful phenomena are displayed. The mechanical effects accompanying the discharge of an electric battery are extremely interesting, but the calorific phenomena it produces are still more so. In these experiments, the universal discharger should always be used to apply, and the quadrant electrometer to afford a comparative measure of the charge employed.

(A.) Place a sheet of white paper on the table, and let a fine iron chain about two feet long, connected with the wires AB of the discharger (364,) lie upon it. Transmit the charge of about six jars, each presenting about a foot of coated surface, through the chain:—on removing the latter from the paper, its outline will be observed marked upon it, with a deep stain at each link. The paper is often burnt through in places if the charge be sufficiently powerful.

(B.) Tie on one end of each rod of the discharger the end of a piece of fine steel wire,* about four inches long, and allow the charge of the battery to pass through it. The wire will undergo combustion, accompanied with a vivid flash of light, being converted into oxide, which is dispersed in all directions.

(C.) Place a slip of gold-leaf between two pieces of paper, allowing its ends to project, and press the whole firmly together by means of the little press of the universal discharger; let its rod AB (364) touch the projecting portions of the gold-leaf, and transmit the charge of a battery through the apparatus. On removing the paper from the press, it will be found stained of a deep purple hue from the oxydized gold, the metal being entirely converted into sub-oxide by the discharge.

(D.) If, instead of using paper, the gold-leaf be pressed between two plates of glass, the latter will be generally broken to pieces, and the gold forced into their substance by the force of the explosion.

367. The facility with which metals are heated by the electric discharge,

* The *watch-pendulum wire* is best for this purpose, that sold as number 32 readily undergoing combustion by a very low charge.

appears to bear a distinct ratio to their conducting powers. As a general rule, it appears that the greater the resistance offered by a metal to the passage of the current, the greater the evolution of heat. The following tabular results of the experiments of Sir Snow Harris on this subject are very interesting.

	Heat evolved.	Resistance.
Lead,	72	12
Tin,	36	6
Iron,	30	5
Platinum,	30	5
Zinc,	18	3
Gold,	9	1·5
Silver,	6	1
Copper,	6	1

368. The electric discharge is capable of communicating transient phosphorescent properties to various bodies over which it passes; thus sugar, fluor spar, and carbonate of lime, continue to emit a green light for some seconds after the charge has passed over their surface. This is best seen by placing the bodies between the ends of the wires of the universal discharger (364), and passing the charge of a large jar through them in a dark room. If a glassfull of water be allowed to rest on the ends of the wires, the passage of the discharge under the gas will render the whole beautifully luminous. The most curious experiment of this kind is made by placing the ends of the wires of the discharger about a quarter of an inch apart and pressing the end of the thumb over them. On then discharging a jar through the wires, the thumb will for an instant appear illuminated with a real light as if suddenly rendered transparent. Eggs, fruit, &c., may thus be rendered luminous.

369. As we have seen that electric induction takes place with very great facility through highly rarefied air (279), we can readily understand the rationale of the Leyden vacuum. This consists merely of an electric jar coated as usual, externally, its interior being exhausted of air, by means of the air-pump, and having a point dipped into its inside, and connected externally with a knob. This apparatus may be used like the common electric jar, induction and discharge readily taking place from the point over its whole internal surface. On charging and discharging in a dark room, the point of the wire in its inside becomes beautifully illuminated with a *star* or *pencil* of rays (339), according as the electricity in the interior of the jar happens to be of the positive or negative character.

Fig. 206.

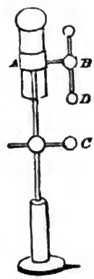
370. The opposite electric states of a charged jar may be beautifully demonstrated by means of the well-known figures of Liechtenberg. To show these, make the resinous cake of an electrophorus (322) dry and warm; draw lines on it with the knob of a positively charged jar, and sift over these places a mixture of sulphur and red lead; on inclining the plate, to allow the excess of the powders to fall off, every line marked by the knob of the jar will be observed covered with the sulphur, whilst the minium will be dispersed. On wiping the plate and drawing figures with the outside of the jar, the sulphur will be dispersed, and the minium collected in a very elegant manner on the lines described by the outside of the jar. The rationale of this experiment is very obvious, the sulphur becomes negatively, and the red lead positively electrified by the friction to which they are necessarily exposed, and on allowing the mixture to fall on surfaces possessing one or the other electricity in a free state, the sulphur will be collected on the

positive, and the minium on the negative portions of the plate, according to the well-known law of electric attraction.

371. The fact that the intensity of a charge has no necessary relation to the quantity accumulated, must never be forgotten in experiments with charged surfaces. Thus, let an ounce phial be coated like an electric jar, and charged in the usual manner, a vivid although minute spark and distinct snap will accompany its discharge. If the finger and thumb of one hand be used to connect the outside and inside coatings, an electric shock will be distinctly felt. Then re-charge this phial, and connect its interior with the knob of a coated jar holding a quart, and unite their outside coatings by means of a wire. Separate the two jars, and it will be found that scarcely the trace of a spark, snap, or shock, will accompany the discharge of either jar, although the actual quantity of electricity must be the same as in the former experiment. The real change undergone being a diminution of tension in the accumulated electricity from its diffusion over a very large surface.

372. The unit-jar contrived by Sir S. Harris enables us to measure with considerable accuracy the comparative quantity of electricity accumulated in a jar. This consists of a small coated phial, insulated on a glass support. Its charge is assumed as the unit of measure. A small coated jar, A, (generally made of a piece of glass tube,) inverted on an insulating support; a wire furnished with a knob at each end, capable of moving through the ball B, is connected with the outside coating of the jar. The wire and ball C are connected with the inside of the jar. Let the outside of the jar A be connected with the prime conductor of the machine in action, and the end of the wire C with the knob of a larger jar. It is obvious that the jar A will be charged negatively internally, its positive electricity thus repelled, entering and charging the interior of the larger jar. After a short time a snap and flash of light occur between D and C from the discharge of the jar AB. The latter again becomes charged, another portion of positive electricity entering the larger jar from its interior, and so on. Thus, assuming the quantity of electricity required to charge one surface of the small jar as unity, the number of luminous discharges occurring between D and C will inform us of the quantity of electricity contained in the larger jar.

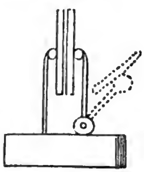
Fig. 207.



373. By means of the action of induction causing the *disguised or paralyzed state* (350) of electricity, we are enabled to detect very minute traces of free electric fluid with facility; instruments arranged for this purpose are called *condensers*. To illustrate their use, touch the prime conductor of an electric machine in weak action, with a disc of metal furnished with a glass handle, as the cover of the electrophorus (322), and bring it towards the cap of an electrometer, the gold leaves will be scarcely affected. Then touch the conductor once more with the disc, holding beneath and parallel to it, at the distance of about a quarter of an inch, a second disc of metal, but *uninsulated*. Remove them in position from the conductor, and touch the cap of the electrometer with the insulated plate, quickly remove the other plate, and immediately the gold leaves will diverge to a considerable distance from each other. In this experiment, the conductor being weakly charged, the plate of the electrophorus employed can only remove a portion of electricity equal to its own surface, a quantity far too small to act upon the electrometer. But on repeating the experiment, with a second plate held parallel to the first, induction comes into play, the electricity which first enters the insulated plate becomes *latent or disguised*, a fresh portion enters, and so on, until the plate of air confined between the two discs of metal becomes charged (351). On

then separating them, the coercing force holding the electricity latent becomes removed, and the absorbed electric fluid readily acts on the electrometer. The most convenient form of the condenser is furnished by the apparatus used in the beginning of this chapter to illustrate the phenomena of induction (356). To use this for a condenser, remove the cork-ball electrometers, and connect one of the plates, as A, with a gold-leaf electrometer (304), by means of a wire. Let the other plate communicate with the earth by means of a piece of chain or wire, then bring the two plates as near as possible to each other, but without allowing them to touch. By means of a wire, or by absolute contact, connect the body whose electricity is to be examined, for a few seconds, with the plate A; then remove it; quickly separate B from A, and instantly the electricity left free in A, will cause the gold leaves of the electrometer to diverge. In this manner, the smallest traces of free electricity can be readily detected.

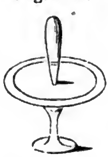
Fig. 208.



374. In the condensers usually made in this country the uninsulated plate is made to move back on a hinge, as shown in the figure, where the electricity and the insulated plate have to be examined.

As it is difficult to place the plates of the condenser as close as is necessary, without their accidental contact often ensuing, it is usual to cover their opposed surfaces with a thin layer of resinous varnish, as a solution of gum-lac in alcohol. When plates thus prepared are used, the layer of resin becomes the charged *dielectric*, instead of the thin plate of air. They are then most conveniently arranged horizontally, and this is the form in which they are generally used on the continent.

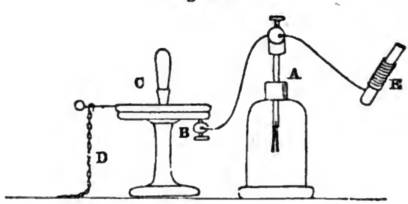
Fig. 209.



375. Aided by these condensing instruments we are enabled to appreciate the disturbance of electric equilibrium in many cases in which, without their aid, we should quite fail to do so. The following are some highly instructive instances of this kind.

(A.) *Detection of electricity excited by combustion.*—Connect a delicate gold-leaf electrometer A with one plate B of the condenser, placing the other, C, in communication with the earth by a chain D. Select a piece of well-burnt charcoal, E, about 4 inches long, and twisting a piece of copper wire firmly round one end, connect it with the cap of the electrometer. Ignite the upper end of the charcoal, and keep it brilliantly burning for a few seconds by aid of a stream of air from a pair of bellows held at a distance; then quickly remove the uninsulated plate C, and the gold leaves will diverge with negative electricity. (Pouillet.)

Fig. 210.



(B.) *Electricity evolved by reduction of salts of silver.*—Remove the charcoal in the last experiment and replace it by a capsule of platinum containing a few grains of oxalate or citrate of silver. Apply the flame of a spirit-lamp until the capsule is barely red hot, and then quickly remove it. The silver will be reduced to its metallic state, and on lifting off the plate C, the gold leaves will separate with negative electricity. (Böttger.)

(C.) *Electricity evolved by decomposition of nitrate of copper.*—Place on the cap of the electrometer a few folds of wet bibulous paper, and place on it a few crystals of nitrate of copper wrapped in a piece of tin-foil pierced full of holes. As soon as the water penetrates the foil from the paper the tin will be acted upon, the nitrate of copper reduced, and red fumes will escape with a copious evolution of heat. The gold leaves will diverge with negative electricity on removing the uninsulated condensing plate. (Böttger.)

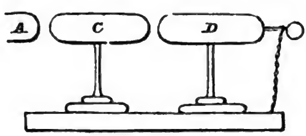
(D.) *Evolution of electricity during the breaking up of crystals.*—Place in the platinum capsule used in experiment B, a few crystals of the double sulphate of potass and copper; apply the heat of a spirit-lamp until they fuse, then remove the lamp. The melted salt will soon solidify into a solid mass. In a few seconds this will begin to break up with a loud crackling noise, and on removing the upper condensing plate the electrometer will be found charged with positive electricity. (Böttger.)

376. When a large jar or battery is discharged by means of a discharging rod without a glass handle, a slight shock is often felt by the person holding it, although he forms no part of the direct circuit. This arises from what has been termed the *lateral explosion*, or more appropriately by Lord Mahon, the returning shock, and is owing to the accumulated electricity not passing through the conducting medium in a single instant of time, although its rapidity is excessive (362). It therefore acts momentarily by induction on the electricities naturally present in the substance in contact with the conductor, as the hand, and thus effects their separation; their recombination taking place the instant the discharge of the jars is completed, producing the slight shock experienced. The lateral explosion is exhibited in the following experiments.

(A.) Charge a jar, and place on the table, with one end in contact with the outside coating, a piece of brass chain. Discharge the jar by means of the discharging rod, and the instant the discharge occurs, the chain, although not forming any part of the circuit, will be illuminated by a spark appearing between each link.

(B). Let an insulated conductor C, be placed about three inches from the

Fig. 211.



end of the prime conductor A, of an electric machine. A conductor connected with the earth by means of a chain, as D, is placed about a quarter of an inch from C. Then A, being positively electrified, decomposes the electricity in C, repelling *its positive* to D, whence it escapes to the earth, so that C is left in a negative state. On discharging A, by touching it with the fingers, a vivid spark appears between D and C; and C is then found to be in its natural electric state.

377. Hitherto, we have considered that negative and positive electricity possess the same properties with regard to conduction and insulation; differing in the appearance of their luminous discharge, the one being accompanied by a star, and the other by a pencil of light (339). A remarkable circumstance has been lately observed, which tends to indicate the probability of the existence of some more important difference between them, instanced in certain bodies being capable of conducting one fluid, and insulating the other, when they are in a state of *extremely weak tension.* These bodies are termed *unipolar;* among them, the flames of alcohol, coal-gas, and sulphur appear to conduct positive electricity, whilst the flame of phosphorus, dry albumen, ivory, and dry soap, conduct negative electricity. Of an approach to this curious class of bodies we have an instance in atmospheric air, which would appear to allow the discharge of positive, to take place quicker than negative electricity (366, G), although Professor Belli has stated the contrary to be the fact.*

378. Good conductors, and non-conductors pass into each other by insensible grades, and indeed rather differ from each other, in one insulating better or worse than another, as they all offer more or less opposition to induction and resulting discharge taking place through them; and at length, such a point of indifference to the discharge of electricity is met with, that bodies are known which allow discharge to take place through them in one direction, and prevent it in another, as in the so-called unipolar bodies discovered by Ermann (377). Many non-conductors insulate when cold, and conduct when heated red-hot, as glass. Others do not acquire their conducting power until they are fused, as in the case of resinous electrics, which allow discharge to take place through them when they are fused, a circumstance first, I believe, mentioned by Cavallo,† and shown to hold good even with electric currents of weak tension, by the elaborate researches of Faraday.

CHAPTER XIV.

ATMOSPHERIC ELECTRICITY.

Atmospheric Electricity, 379. *Electroscopes,* 380. *Diurnal and monthly variation of Electricity,* 381. *Causes modifying,* 382. *Collected by the Kite,* 384. *Sources of Aërial Electricity,* 386. *Lightning,* 387. *Paratonnerres,* 389. *Illustrative experiments,* 390. *Fulgurites,* 392. *Electric meteors,* 393.

379. The atmospheric medium, by which we are surrounded, contains not only *combined* electricity, like every other form of matter, but also a considerable quantity in a free and uncombined state; sometimes of one kind, sometimes of the other; but as a general rule it is always of an opposite kind to that of the earth. Different layers, or strata of the atmosphere, placed only at small distances from each other, are frequently found to be in different electric states.

380. Various pieces of apparatus have been contrived to facilitate an examination of the electric state of the atmosphere. These consist in general of

* Poggendorff, Annalen, t. xl. p. 73.
† Treatise on Electricity, p. 306. London, 1777.

poles elevated about thirty feet into the air, provided with a metallic point at their upper, and insulated at their lower ends; the electric bells (345 D) being frequently suspended from a conductor in contact with such pieces of apparatus, so that by their ringing, they may indicate the presence of free electricity in the conductor.* A long fishing-rod, raised above the highest part of the house, and provided with an insulating conducting wire, furnishes a very convenient apparatus for occasional observations.† The apparatus used by Saussure in his well-known researches, was merely a well-insulated electrometer, provided with a conducting wire about three feet in length, to absorb the electricity from the air.

381. By means of any of these pieces of apparatus, we can readily arrive at a knowledge of the electric state of those portions of the atmosphere nearest the earth. In clear weather, indications of free positive electricity are always to be met with in the atmosphere; this is weak before sunrise, becoming stronger as the sun passes the horizon, and soon afterwards gains its greatest state of intensity; it then rapidly diminishes, and regains its *minimum* state some hours before sunset, after which it once more increases, and gains its second *maximum* state, which then decreases until the following morning.‡

M. Schubler of Stuttgard, to whom we owe the above observations, has remarked that the atmospheric electricity increases from July to January, and then decreases. It is also much more intense in winter than in summer, and appears to increase as the cold increases.

382. Among the causes modifying the electric condition of the atmosphere must be ranked its hygrometric state, as well as, probably, the nature of the effluvia which may be volatilized in any given locality. Thus, Saussure has observed that its intensity is much more considerable in elevated and isolated places, than in narrow and confined situations; it is nearly absent in houses, under lofty trees, in narrow courts and alleys, and in inclosed places. In crowded cities it is most intense in the squares, and upon the bridges. In some places the most intensely electric state of the atmosphere appears to be that, in which large clouds, or dense fogs, are suspended in the air at short distances above the surface of the earth; these appear to act as the conductors of the electricity from the upper regions.

383. Cavallo, from a set of experiments performed at Islington in 1776, ascertained that the air always contains free *positive* electricity, except when influenced by heavy clouds near the zenith. This electricity, he found to be strongest in fogs and during frosty weather, being weakest in hot weather, and just previous to a shower of rain; and to increase in proportion as the instrument used in its investigation is raised to a greater elevation. This indeed necessarily happens, for the earth's surface is, *cæteris paribus*, always negatively electrified, a continual but gradual combination of its electricity with that of the air is constantly taking place at its surface, so that no free positive electricity can be detected within four feet of the surface of the earth.

Mr. Crosse, of Bromfield, collects and examines the atmospheric electricity, by means of wires, insulated and supported by poles and by the trees in his park. When these conductors are about one-third of a mile in length, he has frequently succeeded in collecting sufficient electricity, to charge and discharge a battery of fifty jars, containing seventy-three square feet of coated surface, twenty times in a minute, accompanied by reports as loud as those of a cannon.§

* Phil. Transactions, 1792.

† Cavallo, p. 370.

‡ Becquerel, Traité, t. iv. p. 84.

§ Sturgeon's Journal, vol. i. p. 139.

384. The first satisfactory attempt to collect the electricity of the upper regions of the air, was made by Dr. Franklin in North America, in 1752, although it must be observed that a short time previously, Dalibard, in France, had by means of a long-pointed conductor, raised in Marly-la-Ville, succeeded in obtaining vivid sparks of atmospheric electricity. Dr. Franklin raised into the atmosphere a kite, formed by stretching a silk handkerchief across two rods of light wood, and with this, when the string had been rendered sufficiently moist by the falling rain to conduct electricity, he obtained a copious succession of sparks, from a key, fastened to the end of the string. Subsequently, M. Romas, in France, by increasing the length of the string, obtained flashes of electric light from his apparatus, ten feet in length, accompanied by a report as loud as that of a pistol. Shortly afterwards Professor Richman, of St. Petersburg, was struck dead by a discharge from an apparatus, similar to that of M. Dalibard, with which he was experimenting.

Cavallo, in 1777, raised an electric kite repeatedly in the neighborhood of London, and obtained an enormous quantity of electricity; he found that the electricity frequently changed its character, as the kite passed through different aërial layers or strata.

385. Perhaps the most ingenious mode of investigating the electric state of the upper regions, is by means of the apparatus used by MM. Becquerel and Breschet, on the great St. Bernard.* These gentlemen placed one end of a cord covered with tinsel, about ninety yards in length, on the cap of an electrometer, and tying the other to an arrow, they projected it, with the aid of a bow, into the air, and they found that the gold leaves diverged in proportion as the arrow ascended into the atmosphere.

Fig. 212.

386. The probable cause of the free electricity in the air has been referred to various sources; the phenomena of animal and vegetable life, as well as chemical action, have been called in to explain its origin. Among others, the evaporation of water, and other fluids, constantly taking place on the earth's surface, may certainly be regarded as one of the sources of atmospheric electricity. The evolution of electricity by evaporation, may be readily proved by placing on the cap of a gold-leaf electrometer a small metallic cup containing water, in which some common salt has been dissolved. On dropping into it a piece of hot cinder, the vapor will arise copiously and carry off positive electricity, leaving the cup negatively electrified, with which electricity the gold-leaves will diverge. If water, containing a minute portion of an acid, be substituted for the weak brine, the reverse will occur, the gold-leaves diverging with positive electricity, the vapor being negatively electrified.

Hardly venturing to differ from so high an authority as Dr. Faraday on any subject connected with electrical science, I still cannot help expressing my conviction that the electricity evolved in these experiments is due really to eva-

* Traité de l'Electricité et du Magnétisme, t. iv. p. 110.

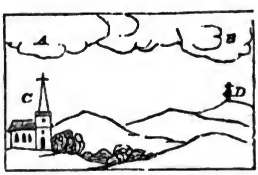
poration, and not to friction, as I really regard this as a very distinct case from the copious disengagement of electricity in the hydro-electric machine, and feel inclined to agree with Mr. Armstrong, in regarding evaporation of fluids as one at least of the sources of the electricity of the atmosphere.

387. The clouds, consisting of immense masses of aqueous vapor, are tolerably good conductors of electricity, and consequently, contain a considerable quantity of the latter in a free state. There can be but little doubt that a cloud consists of an aggregation of minute hollow vesicles of aqueous vapor filled with air. These when similarly electrified do not repel each other, and fly apart, unless they are quite beyond the inductive influence of the earth, or of any nearer body. Thus, a glass feather fixed in one of the holes of the prime conductor of an electric machine will appear animated, every fibre mutually repelling each other. But if the hand, or a large brass ball be held near it, then the fibres will fall together, lose their appearance of repulsion, and bend towards the hand or ball under the inductive, and consequently attractive influence exerted by them.

388. Two clouds, being in different electric states, act upon each other through the particles of the intervening dielectric, or air, like the inducing surfaces or metallic coatings of a charged jar, and when sufficiently near to each other, *discharge* occurs, producing the vivid flash well-known as lightning, generally accompanied by the loud reverberating sound of thunder. When, on the other hand, induction, and consequent *charge* takes place through the air, between an electrified cloud and the earth, an explosion or *discharge* ensues, when the intervening particles of the dielectric are so arranged as to admit of its occurring; producing a second, and much dreaded form of lightning. This mode of establishing an equilibrium between the oppositely electrified bodies, often ensues through the medium of the nearest most prominent conductor, which, if a tree, is often riven in sunder; if a building, is frequently dashed in pieces; and if an animal, severely injured or even killed.

389. Several instances have occurred of the fatal effects of a tempest having been exerted on animals at a considerable distance from the spot where the most serious results have taken place, and where the violence of the storm appeared to have been chiefly exerted. This will readily admit of explanation, on the supposition of a lateral explosion or returning shock (376) having occurred. Thus, if A B be a large cloud, positively electrified, approaching at its end, A, within striking distance of the church-steeple C, the extremity B

Fig. 213.



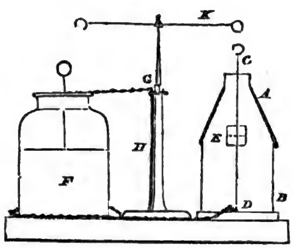
will, by its inductive action, decompose the electricities present in any object at D, as a traveller for example, repelling the positive to the earth, and leaving him in a negative state. When A has approached sufficiently near to C, an explosion will occur, and electric equilibrium will ensue. B being thus left unelectrified, no longer exerts a coercing force on the negative electricity in D, which, attracting the positive electricity previously repelled by B, causes

it to rush with violence into D, producing *discharge*, and a restoration of electric equilibrium, with such mechanical force, however, as too often to kill the unfortunate individual situated at D.*

390. Science, and mankind generally, must ever remain debtors to the ingenuity of Dr. Franklin, for proposing, at least, a partial protection against these dreaded effects of the tempest, in the invention of the *paratonnerres*, or lightning rods. These consist of metallic conductors, of sufficient thickness, usually fixed against the sides of the building they are destined to protect, their upper extremities extending some feet above it, and terminating in a point, which is best constructed of some metal not liable to oxydation. The lower end is buried in the earth, to the depth of a few feet. For ships, flexible paratonnerres, composed of copper chain, or slips of that metal, are fixed to the masts, and reaching from their highest points to the outside of the keel of the vessel, so as to conduct the electricity harmlessly to the water in which the vessel floats. Whatever form is used, one general precaution is necessary, *that all and every portion of the paratonnerre should be as perfectly continuous as possible*, for wherever a break or interruption occurs, the electric fluid, in rushing from one portion to another, is liable to produce the very danger which these instruments are intended to avert.

391. To illustrate some of these positions, the thunder-house as it is termed, was invented by Dr. Franklin. AB is a piece of hard dry wood, cut into the shape of the gable end of a house, with a brass rod, terminating in a ball at

Fig. 214.



c, fixed aginst its side, and terminating at D in a hook. At E this conductor is interrupted by a block of wood, fitting loosely into a cavity made to receive it, having a wire fixed across it; so that when E is fitted in its place, as in the figure, the conductor CD is perfect; but when placed in the opposite direction, as shown by the dotted line, the paratonnerre CD is interrupted in its centre.

Exp. (A.) Charge the jar F; connect its outside with the hook at the end of D, and its knob with the pointed wire supported on its *insulating* stand H, and bearing on its apex the brass rod K, terminating in balls, and moving on it in any direction, as on a pivot. Place the window E in its place, so that the brass conductor may be continuous, and cause K to revolve, so that one of the balls terminating it may pass within half an inch of C. The jar will be discharged, and the window E remain unmoved.

(B.) Repeat the last experiment, with the window E placed so that its wire may be at right angles to the axis of the wire CD. On discharging the jar as

* See Traité Elementaire de Physique, par M. L'Abbé Hauy, p. 434. Paris, 1806.

before (A) the effects of the explosion will be exerted on E; and will project it with violence from the cavity into which it fits.

(C.) Let things be arranged as in Exp. (B), but remove the knob on C, and leave the paratonnerre pointed. On allowing K to revolve the jar will be *silently* discharged. The electric current, during this gradual discharge by the point, never acquiring sufficient tension to act energetically on E, although it was displaced with violence when D terminated in a knob.

(D.) The protecting influence of pointed conductors is more strikingly shown by the electrical toy, called the powder magazine, in which the interrupted portion of the conductor reposes in a mass of gunpowder, placed in a wooden model of a house. If the jar be discharged whilst the paratonnerre terminates in a point, the powder is unaffected; but if a knob be screwed on, the discharge explodes the powder, and blows the model to pieces. In repeating this experiment, a piece of wet string should be used to connect the jar with the base of the paratonnerre, for reasons already mentioned (365 D).

392. When lightning strikes a sandy soil with sufficient force, it often penetrates to the depth of several feet, forming the gravel into a sort of tube, known as a *fulgurite*, and in almost every instance has been found to terminate in a subterranean reservoir of water.

The lambent lightning so common in the sultry autumnal evenings is unattended with the sound of explosion, and often appears in the most opposite regions of the sky. It has been in many cases traced to the restoration of electric equilibrium disturbed by storms actually below the horizon.

393. The well-known meteoric appearances so frequent on the pointed masts of shipping, known as Castor and Pollux, the feu de St. Elm of the French, and Elmsfeuer of the Germans, appear to depend on the slow discharge of atmospheric electricity by the pointed masts of the vessel.

The beautiful aurora borealis, so frequent in the north of Europe, and of late years not of unfrequent occurrence in the neighborhood of the metropolis, depends in all probability, on the passage of electricity through a highly rarefied medium. From the calculations of Mr. Cavendish, it is probable that the aurora usually appears at an elevation of about seventy one English miles above the earth's surface; at which elevation the atmosphere must be of but $\frac{1}{148,387}$ times the density of that at the earth's surface, a degree of rarefaction far above that afforded by our best air-pumps. As electricity is diffused in a quantity nearly proportionate to the elevation above the earth's surface, it appears very probable, that under favorable circumstances, it would appear luminous to us, in the vast regions of rarefied air terminating our atmosphere, in a manner analogous to that in which it appears on an infinitely smaller scale in an air-pump vacuum. When the discharge of a large jar is effected through a long tube filled with rarefied air, it appears luminous, not in flashes, like the luminous aurora (340), but in a condensed form, like a ball of fire, falling through the tubes; very closely imitating in appearance that of some other meteors, well known as *falling* or *shooting stars*.

CHAPTER XV.

ELECTRICITY EXCITED BY CHEMICAL ACTION. (GALVANISM, OR VOLTAISM.)

Apparent excitation of electricity by contact, 394—*depending on chemical action*, 395. *Chemical affinity referable to electricity*, 396. *Table of simple bodies*, 397. *Action of acids on zinc and copper plates*, 398. *Cause of this action—molecular changes*, 399—*results in the evolution of electricity*, 400. *Electrometers*, 401. *Generating and conducting elements*, 407—409. *Gain of power by absorption of hydrogen*, 410. *Excitation by two fluids*, 411. *Prof. Daniell's arrangement*, 407. *Electro-type*, 408. *Excitation of currents by one metal*, 409. *Effects of currents from a single pair*, 410. *Volta's pile*, 413—*source of electricity in*, 414—*batteries*, 415—419. *Prof. Ohm's formula*, 420. *Luminous discharge of battery*, 423—*transfer of ponderable matter during*, 424—*calorific effects of*, 425 —*refrigerating effects of*, 426. *Positive and negative ends of battery*, 429—*water batteries*, 430. *Dry piles of De Luc and Zamboni*, 431. *Prof. Grove's gas battery*, 433.

394. It has been already mentioned, that two plates of glass, when pressed together, and suddenly separated, assume opposite electric states (310). The same thing occurs when two disks of different metals are similarly treated. To demonstrate this, take a plate of copper and one of zinc, about four inches in diameter, each furnished with a glass handle fixed in its centre; connect a gold-leaf electrometer with the plate A of the condenser (373), allowing B to be connected with the earth. Press the copper and zinc plates together, holding them by their insulating handles; suddenly separate and apply one of them to the plate A of the condenser; again press them together, having previously touched them with the finger to restore their electric equilibrium, and reapply the same plate to the conductor. Repeat this about six times, then draw back the uninsulated plate B, and the gold leaves of the electrometer will diverge with *positive* electricity if the zinc, and with *negative* if the copper plate has been applied to the condenser.

395. The development of free positive in the zinc, and of free negative electricity in the copper plate, was attributed by the illustrious discoverer of the fact, Prof. Volta of Pavia, to a peculiar electromotive force, under which, metals, by simple contact, tend to assume opposite electric states. This theory has now but few supporters, in consequence of the mass of evidence that has been opposed to it by Fabroni, De la Rive, and our illustrious countryman, Faraday, to whom we are so largely indebted in this branch of science. These philosophers have very satisfactorily proved, that whenever electricity is developed during metallic contact, it is owing to some chemical action undergone by the most readily oxidizable metal. So rigorously has this been demonstrated, that it may be stated as a general law, *that no chemical action occurs, unaccompanied by disturbance of electric equilibrium, and consequent development of free electricity*, although it is fully possible for such to occur without our being able to detect it, for unless the electricity evolved is in sufficient quantity to circulate as a current, or of sufficient tension to be collected by a condensing plate and act on the leaves of an electrometer, it may escape the evidence of our senses.

396. In every chemical combination, whether saline, haloid, or of still more

complex nature, the force by which the elements, both proximate and ultimate, are held together, appear to bear a close relation to their electric state, and their separation is generally accompanied by the evolution of a current of electricity of low tension. So general is this fact, that the discoveries of Dr. Faraday have certainly very closely pointed out the probability of chemical affinity being after all but a modification of electric attraction; an opinion previously adopted, with some limitation, by Davy, Berzelius, and others no less deservedly celebrated in this branch of experimental science.

Among the ultimate elements with which chemistry has made us acquainted, there are twenty-two which are characterized by their electro-negative, and thirty-two by their electro-positive state in relation to each other.

I. Electro-negative.

Oxygen	Fluorine	Tungsten
Hydrogen	Carbon	Antimony
Nitrogen	Boron	Tellurium
Sulphur	Silicon	Titanium
Phosphorus	Selenium	Tantalium
Chlorine	Arsenic	Vanadium.
Bromine	Chrome	
Iodine	Molybdenum	

II. Electro-positive.

Gold	Tin	Yttrium
Platinum	Lead	Glucinium
Iridium	Cadmium	Aluminium
Osmium	Zinc	Magnesium
Palladium	Nickel	Calcium
Rhodium	Cobalt	Strontium
Silver	Iron	Barium
Mercury	Manganese	Lithium
Copper	Lantanium	Sodium
Uranium	Cerium	Potassium.
Bismuth	Zirconium	

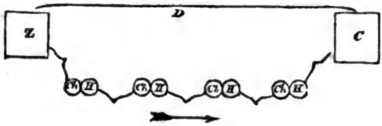
These substances are, it must be remembered, negative or positive only in relation to each other, and their mutual chemical affinities appear to be in the ratio of the intensity of the difference of their comparative electric states. Thus potassium has the greatest affinity for oxygen of any other substance in nature, and, accordingly we find that, whilst the former is in its combinations powerfully positive, the latter is as energetically negative. In the list of negative bodies every element is to be regarded as negative to all below, and positive to all above it in the list: thus hydrogen is negative with regard to nitrogen, but positive with regard to oxygen. A similar observation applies to the list of electro-positive elements.

397. Let a piece of zinc be amalgamated by immersing it in a little dilute sulphuric acid, and rubbing a few globules of mercury over it with a piece of cork. Fill a glass with a mixture of one part hydrochloric acid and six of water, and place the amalgamated zinc in it. The brilliant surface of the zinc almost immediately assumes a grayish tint from its becoming covered with myriads of excessively minute bubbles of gas. These consist of hydrogen, arising from the decomposition of the acid, its chlorine uniting with the

zinc, and the hydrogen for which the metal has no affinity, mechanically adheres to its surface, and thus by a gaseous covering shields it from the further action of the acid. Then immerse in the fluid a rod of any metal standing above zinc in the list (396), as a piece of copper or silver; no obvious action will occur until it touches the surface of the zinc, when in an instant a torrent of bubbles of gas is evolved from the copper, as though it were undergoing solution, no evolution of gas from the zinc taking place. The copper, however, remains chemically unacted upon, and the zinc is alone dissolved, and consequently mere chemistry is incapable of affording a satisfactory solution to the curious phenomena just described. From the facts already stated, we see that the copper and zinc, being placed in contact, assume opposite electric states, from the chemical action of the fluid on the most oxidizable metal.

398. The origin of the action itself must be referred to an exalted attraction of the zinc for the chlorine, which becomes at last so intense as to enable it to take the latter from the hydrogen with which it was previously combined. But the hydrogen is evolved at a distant part of the fluid, viz. from the surface of the copper, which may be even several feet from the zinc plate, and the intermediate portion of fluid undergoes no visible change of any kind during this transfer of hydrogen from the zinc to the copper plate. This is explained by the fact that at the moment the atom of hydrochloric acid is decomposed at the zinc surface, and the chlorine combined with the latter, a current of positive electricity leaves the zinc, and by a kind of convective force carries with it the atom of hydrogen which was deserted by the chlorine. This atom, instead of being itself carried onwards, decomposes the first atom of hydrochloric acid in its path, uniting with the chlorine; this second atom of hydrogen still urged onwards by the convective force of the current in its turn seizes the chlorine of another atom of hydrochloric acid, causing its hydrogen to be evolved, and this action continues until the electric current reaches the copper plate, where it leaves the last atom of hydrogen, which, becoming passive, is here set free. As these changes occur instantaneously and invisibly, they altogether escape detection by our senses. The following diagram, in which C is the copper plate, Z the zinc one, connected by a wire D; H and *ch*, respectively represent the atom of hydrogen, and chlorine, will perhaps render these changes more intelligible; the arrow showing the direction of the positive current through the fluid.

Fig. 215.

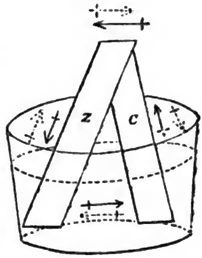


As no one electric element can be set free without the other with which it was combined being set in motion; so whilst a current of positive fluid passes from the zinc to the copper through the liquid, and thence back to the zinc through their points of contact, a negative current is always passing in the opposite direction, or from the copper to the zinc.

399. The metals employed need not be in actual contact in the fluid, for if connected by a conductor out of the fluid, the effects above described take place.

This conductor may be a wire, or be constituted by the plates themselves, by so inclining them that they may lean against each other, as in the marginal figure, where c is the copper and z the zinc plate; the dotted arrows representing the direction of the *negative*, and the entire ones that of the *positive* current.

Fig. 216.



That such currents do really exist will presently be shown to be beyond a doubt. As a tolerably satisfactory proof, however, the well-known calorific effects of electricity may be observed by separating the plates cz at the upper part, and connecting them by a piece of very fine platina wire, half an inch in length. This, if the plates be about four inches long and two broad, will become brilliantly ignited, from the electric discharge taking place through it, as long as chemical action continues. In repeating these experiments, ordinary rolled zinc may be substituted for the amalgamated metal, but the phenomena described will be masked by chemical action ensuing at the zinc surface.

400. The electricity thus evolved, although weak in intensity, is considerable in quantity; and for many important experiments a pair of zinc and copper plates, excited by dilute sulphuric acid, constitute a valuable source of electricity. These *electromotors*, as they are termed, are readily made by placing a piece of sheet copper, a foot long, and six inches wide, having a copper wire for a conductor soldered to it, in the inside of an earthen jar; a piece of sheet zinc, nine inches long and six wide, furnished with a similar conductor, is rolled into a cylindrical form amalgamated (397). and covered loosely with a fold of linen, so that when placed in the jar, metallic contact between it and the copper may be prevented. The jar being nearly filled with dilute sulphuric acid, the plates are immersed and the current of electricity evolved, directed by the conducting wires to any point the operator pleases.

401. In all cases in which electricity is evolved by the chemical action of a fluid on one of two metals in metallic contact and exposed to its influence, it is necessary, as already stated, that one of the metals should be more oxidizable than the other, or, in other words, more positive in its electric relations. We may thus conveniently separate the metallic elements of a voltaic circle into a *generating* plate and a *conducting* plate. The former being alone active in determining the evolution of electricity, the latter acting chiefly as a surface on which the convective positive current may discharge itself. Unless the fluid in which the metals are immersed is decomposable by an electric current, it has not the power of exciting one; hence it must be a compound, consisting of at least two elements. Thus, water acidulated by any of the mineral acids, or in which an alkaline salt is dissolved, is powerfully active in these circumstances in evolving an electric current.

A second zinc plate can never act as a conducting plate, because it will itself tend to generate a current which will oppose the first in direction. If, however, a perfectly smooth plate of rolled zinc be used as a conducting plate to one of rough cast zinc, as a generating plate, a weak current will be evolved.

402. If, instead of immersing the zinc and copper plates in dilute acid (397), they had been placed in water only, chemical action and evolution of electricity would have ensued, but with much less energy: the electricity being evolved in very small quantity, in consequence of the very low intensity of the chemical action of water on the zinc. In a solution of common salt, the effects are more obvious, the chloride of sodium being decomposed and

chloride of zinc formed—the chlorine being the negative and sodium the positive elements (396); and electricity is evolved from the decomposition of the salt in the same manner as it was from that of the water by hydrochloric acid (397).

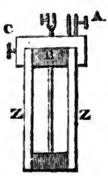
The quantity of electricity evolved, increases with the surface exposed to the chemical action of the fluid in which it is immersed; and hence gigantic plates have been constructed for the purpose of obtaining an immense quantity of electricity. Mr. Pepys had an electromotor made for the London Institution, consisting of a copper and zinc plate, each fifty feet long and two wide, rolled into a coil, with horse-hair ropes between them to prevent their touching each other. About fifty gallons of dilute acid were required to act upon these plates, and the torrent of electricity evolved was truly immense.

403. Bearing in mind, that the excitation of electricity bears a direct relation to the amount of chemical action exerted on the most positive metal employed, and increases with the extent of surface acted upon; we are capable of increasing the evolution of electricity to a considerable amount by a proper arrangement of apparatus. It is found from experiment that a considerable advantage is gained by causing the conducting or negative element to *surround* the generating or positive, so as to present a surface opposed to both sides of the latter, a fact depending in all probability upon the greater extent of the conducting surface ensuring the whole of the evolved electricity assuming the form of a current. For it is fully possible for an enormous quantity of electricity to be excited, and yet but little appear in the form of a current, either from excessive local action or a bad arrangement of apparatus. On this account, in all well-constructed electromotors, the zinc or exciting element is placed in the centre with regard to the copper.

It has been stated that an increase in the quantity of the evolved electricity ensues when either the zinc or copper exceed each other in size, and that the quantity of excited electricity is a minimum when the metals expose an equal extent of surface. If the zinc plate be the largest, the maximum effect is said to be obtained when it is seven times larger than the copper; and if the latter be the largest plate, that the maximum evolution of electricity occurs when it is sixteen times larger than the zinc plate. In the former case the quantity of electricity is three, and in the latter four and a half times greater than when the plates of copper and zinc are of equal size. Prof. Daniell has however shown, that if the diameter of the mean section of the active fluid remains the same, and all interfering causes from deposition on the conducting plate be removed, it matters but little, so far as the resulting current is concerned, whether the generating or conducting element is the largest.

404. A convenient and certainly powerful arrangement has been proposed by Mr. Smee, consisting of two plates of amalgamated (397) zinc, zz, clamped to a piece of wood B by means of a bent piece of brass C, and furnished with a binding screw at A. Between the plates of zinc is fixed a thin plate of silver connected at its upper end with another binding screw. This plate of silver is covered with a thin layer of platinum, by immersing it for a short time in a solution of chloride of platinum whilst connected with the negative end (396) of a voltaic battery. The platinum is deposited on the plate in the form of a fine powder, and from the myriads of conducting points thus found by the inconceivably minute particles of reduced metal, the evolution of the hydrogen gas is greatly facilitated. An arrangement of this kind, placed in a pint jar of dilute sulphuric acid, becomes an excellent and efficient source of electricity, especially available for electro-magnetic researches.

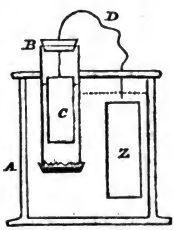
Fig. 217.



405. In the arrangements of apparatus above described, a considerable loss of electricity occurs during the evolution of the hydrogen. To prevent this, certain means have been had recourse to, for the purpose of absorbing the hydrogen by employing it to reduce metallic oxides, or by combining with the oxygen of any highly oxidized fluid, as nitric acid. If the plates of zinc and copper, instead of being acted upon by a dilute acid, be immersed in a solution of sulphate of copper, chemical decomposition and consequent evolution of electricity will occur. No gas is in this case evolved, as the sulphate of copper is alone decomposed; the sulphuric acid and oxygen acting on the zinc forming the sulphate of that metal, which is dissolved by the water; the copper being deposited, in a metallic state, on the surface of the copper plate used. Thus the battery or electromotor may be advantageously excited with a solution of sulphate of copper, instead of dilute acid.

406. In all these arrangements, both plates are immersed in the same exciting fluid; but considerable advantage is gained by employing two different fluids. This mode is founded on facts long known, but first applied to the construction of electromotors by Professor Daniell.* The theoretical action of these arrangements is readily explicable: let A be a vessel filled with a solution of common salt (chloride of sodium); B a tube immersed therein, furnished at its lower part with a diaphragm formed of a piece of bladder, and filled with a solution of sulphate of copper; a plate of copper C, connected with one of zinc Z, by the wire D, are immersed in the two fluids. The generating or positive element Z decomposes the chloride of sodium, uniting with the negative chlorine, forming chloride of zinc, and repelling the positive sodium, which passes through the bladder diaphragm under the convective influence of the excited current, to reach the negative plate C; here it enters the solution of sulphate of copper, which it decomposes, uniting with the sulphuric acid and oxygen to form sulphate of soda, and setting free copper, containing free positive electricity, which is given up to the plate C, and passing along the wire D to Z, decomposition goes on as before: the atoms of sodium and copper first set free, are not those which are ultimately active in effecting decomposition, or in being deposited on the conducting plate; the same series of molecular changes occur as in the case of the decomposition of hydrochloric acid already described (398). In this apparatus, after the current has continued passing for a sufficient time, we shall find the fluid in A converted partly into chloride of zinc, and that in B into sulphate of soda; whilst the beautiful crystals of copper deposited on C, will be found to bear that relation to the quantity of zinc dissolved to form the chloride, which the atomic weight of copper does to that of zinc. If the wire D were cut across in the middle, chemical decomposition and evolution of electricity would cease, until they were united by being placed in contact, or connected by means of a good conductor,

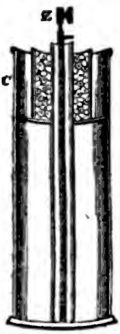
Fig. 218.



407. As in this apparatus (406) the inductive action of the two plates on each other is limited by the area of the base of the tube B, through which alone a current can pass from the generating to the conducting plate through the fluid, the evolution of electricity will be increased by replacing the tube B by a bag or reservoir of animal membrane, as bladder; and this constitutes a form of apparatus frequently employed. A piece of sheet copper is rolled into a cylindric form, and placed in a bladder fastened round its upper part

* Philosophical Transactions, 1836.

Fig. 219.

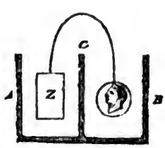


by a piece of string; the whole being placed in a jar, containing a concentric cylindric roll of sheet zinc; a metallic wire, or conductor, is soldered to each plate. A solution of sulphate of copper is poured into the bladder, and one of common salt, or sulphate of soda, is placed in the jar, exterior to the bladder, so as to act upon the zinc plate.

The inconvenience of this arrangement arises from the zinc being placed on the outside of the copper, which necessarily produces, as Professor Daniell has shown, a certain loss of power;* accordingly, the arrangement used by that gentleman consists of a cylinder of amalgamated zinc, z, placed in the centre of a hollow cylinder of copper, c; the former being surrounded by a tube of ox-gullet, or, what answers the purpose exceedingly well, a cylindric bag of compact sail-cloth, previously soaked in water. The exciting fluid acting on the zinc, is a mixture of one part sulphuric acid and eight of water, the copper cylinder being filled with the same mixture saturated with sulphate of copper. On connecting the two plates, by means of a wire, the zinc plate decomposes the water, its hydrogen influenced by the convective force of the positive current passes through the membranous bag, towards the copper plate, where it is not evolved, but aids the decomposition of the sulphate of copper; uniting with the oxygen of the oxide to form water, and setting free the copper to be deposited in beautiful crystals, on the surface of the copper element.

408. The copper deposited in these experiments upon the negative plate is found, if the electric action be not too intense, to be compact, firm, and even malleable; and on separating it from the surface on which it has been deposited, it will be found to present a perfect fac-simile of every mark and scratch existing on the surface of the negative plate. This has led to the discovery of the beautiful art of electro-typing, by which exact copies of almost anything whose surface is capable of being rendered a tolerable conductor, may be made in copper. Many contrivances have been made for the purposes of facilitating the deposition of copper from its solutions, and will be found described in the numerous popular treatises on the subject.† The simplest apparatus consists of an earthen or varnished wooden vessel, AB, divided vertically by means of a porous diaphragm, c, of wood or earthenware, thus forming two cells; one of these, as A, is filled with a very weak solution of common salt, the other, B, with a solution of sulphate of copper. In the generating cell, A, is immersed a plate of zinc, z, connected by a wire with the medal, &c., to be copied, which is placed in B. This medal should be covered with a resinous varnish or some non-conductor, except on the surface to be copied. An electric current is soon set up, and both solutions are decomposed (406), metallic copper being deposited freely on the face of the medal; and when the deposit has attained sufficient thickness, it will, if adroitly removed from the surface of the metal, present a most accurate and beautiful copy of the original. It is scarcely necessary to say that fresh crystals of sulphate of copper should be dropped into the cell B, in proportion as the fluid loses its color by depositing its copper.

Fig. 220.

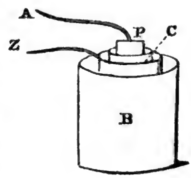


* Philosophical Transactions, 1838, p. 41, et seq.
† See Electrotype Manipulations, by C. V. Walker

In this manner, by careful manipulation, most accurate copies of engraved copper plates can be readily made, and those beautiful products of art be multiplied to an almost unlimited extent. Even the inconceivable delicate tracings of Daguerre's exquisite pictures can be copied by the electro-type. Where the object to be copied is not metallic, it may be rendered a sufficiently good conductor by covering it with a thin layer of finely powdered plumbago, and thus casts made of wax or sulphur can be readily copied in copper.

409. By far the most energetic voltaic arrangement in which the hydrogen is absorbed is that proposed by Mr. Grove. Various constructions of this excellent contrivance are met with. They consist essentially of a slip of platinum-foil P, furnished with a conducting wire A, immersed in a cylinder of porous earthenware, C, filled with strong nitric acid (sp. gr. i. 33). This cylinder is surrounded by a roll of amalgamated zinc, having a conducting wire Z soldered to it, and placed in an earthen or glass jar B, containing dilute sulphuric acid, (1 acid to 8 water.) The hydrogen separated when AZ are connected from the decomposed water, is not evolved as gas, but combines with some of the oxygen of the nitric acid, reducing it to deutoxate of nitrogen, which partly dissolve in the acid, giving it a green or blue color, some escaping, forming red fumes from combining with oxygen of the air to form nitrous-acid. According to Jacobi, with equal surfaces of platinum and copper, the apparatus of Mr. Grove is about seventeen times more powerful as a source of electricity than that of Prof. Daniell (407). With a nitric acid battery capable of being contained in a two-ounce jar, fine platinum wire may be brilliantly ignited.

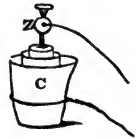
Fig. 221.



The excellence of Mr. Grove's arrangement is owing, not only to the absorption of hydrogen, but to the excellent conducting nature of the fluid employed, and to the remarkable facility with which nitric acid undergoes decomposition.

410. The expense of platinum is a serious drawback to the use of these arrangements; to obviate this, Prof. Bunsen has proposed substituting cylinders or plates of carbon for the platinum. He made these, by strongly and repeatedly heating a mixture of pulverized coals and coke, and thus obtained a porous mass capable of being easily worked into any required form. These carbon batteries are said to be equally powerful with those of platinum. I find they may be constructed from the best black-lead crucibles after strongly igniting them for a short time. For this purpose a cylinder of amalgamated zinc, Z, is placed in a porous cylinder containing dilute sulphuric acid, and immersed in the crucible C filled with nitric acid; a wire coiled tightly round acting as a conductor. Such an arrangement, although powerful, is, however, certainly far inferior to Mr. Grove's apparatus, probably on account of the earthy matter which is always present in these crucibles rendering them imperfect conductors.

Fig. 222.

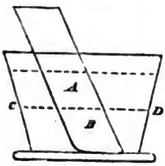


411. It is by no means necessary to use two different metals to obtain an electric current; for if but one be used whose surface is so constituted as to be unequally acted upon by the fluid in which it is immersed, electricity will be evolved; the portion of the metal most acted upon becoming the positive element. Thus, as we have already seen, a plate of rolled, and one of cast zinc, constitute an effective voltaic arrangement (401): as does also a plate of new clean zinc, with one which has been previously

corroded by an acid. A new and a corroded plate of copper acted upon by nitric acid, also evolves electricity.

411. If but one metal of equal surface be used, no electricity will be evolved, unless acted upon by fluids exerting different chemical actions upon it. Thus, a plate of smooth iron acted on, on one side by dilute sulphuric acid, and on the other by water, sulphate of copper, &c., constitutes an effective arrangement.

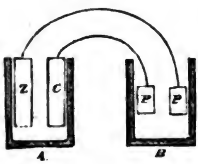
Fig. 223.



Let a plate of copper, AB, be placed in a glass vessel, and a saturated solution of sulphate of copper poured in up to the line CD, so that about one-third of the plate may be immersed. On the surface of this fluid slowly pour some very dilute sulphuric acid, or weak salt and water; taking care that the fluids do not mix. Under these circumstances the upper part of the plate, A, will be slowly acted upon by the sulphuric acid; the lower end B becoming the negative element, decomposition of the sulphate of copper slowly takes place, and the metal becomes deposited in a crystaline form, on that part of the copper plate which is immersed in the sulphate of copper.

412. If the conducting wires belonging to a single pair of plates be furnished with platina terminations, and instead of being metallically connected, be immersed in the same solution as the plates themselves, no current will pass.

Fig. 224.



The electricity excited in the cell A, will not be able to pass from P to P in the cell B, because the current is too weak to overcome the affinities of the elements of the liquid in B for each other, and it cannot traverse the fluid save by effecting molecular changes in the elements of the compound present. We may, however, induce the current to pass, either by replacing the fluid in B by one which is more readily decomposable, or by calling in the aid of the affinity of the positive conducting wire for one of the elements of the liquid in B.

To illustrate the first case, let A and B be both filled with dilute sulphuric acid, and the current will not pass through B. Replace the contents of B by a solution of iodide of potassium, a salt of ready decomposition; the current will now readily pass, decomposing the iodide, evolving the iodine at surface of the platina plate connected with the copper in A, and if a little starch be added to B, the evolution of the iodine will readily be detected by the formation of a splendid blue precipitate of iodide of amidine.

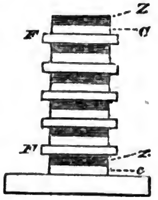
The second case may be illustrated by filling A and B with dilute sulphuric acid, and letting the conducting wires be of copper, with their naked terminations immersed in B. The current will now pass, and bubbles of hydrogen gas will be evolved at the end of the wire connected with the plate Z. Here, although the current *per se* could not effect a separation between the elements of the water in B, yet when aided by the affinity of the copper composing the positive conducting wire for oxygen, it succeeded in decomposing water and traversing the fluid.

413. In all these various modes, we are enabled to cause the evolution of electricity in considerable quantities, but in a state of extremely low tension. To Prof. Volta of Pavia, we are indebted for the discovery of a mode of increasing its tensile state, and by the contrivance of his magic pile, putting into the hands of philosophers an instrument of analysis and investigation, infinitely exceeding, in its wonderful effects, any of the means of experimental research

before discovered. Omitting the earlier experiments of Volta, or the mode of reasoning by which he was led to this discovery, as out of place in a work of this description, it will be sufficient to observe that, by combining the action of several pairs of plates, an infinite increase of tension and power is gained.

To understand the construction of the voltaic pile, place a plate of copper, c, on the table, and on this one of zinc, z. A piece of thick flannel F, moistened with a dilute acid, brine, or even water, is placed on the zinc; a plate of copper on this, and so on; copper, zinc, wet flannel—copper, zinc, &c., until any number of alternations are used. Place the whole pile on an *insulated* stand, and connect the lower plate c with the condenser (373), connected with an electromotor; the gold leaves will diverge with negative electricity. Then connect the upper plate z with the condenser, and the leaves will diverge with positive electricity. In an insulated pile of any number of alternations the electric tension of each kind of electricity is observed to increase from the centre to the extremities.

Fig. 225.



414. If a pile or battery be constructed like the one originally contrived by Volta, providing there are at least thirty alternations, and any person touching the top and bottom of it at the same instant with his moistened hands, the electricity accumulated at each end of the pile will discharge itself through his arms, producing an *electric shock*. If a piece of well-burnt charcoal be placed upon the uppermost plate of the pile, and a wire communicating with the lowest be brought in contact with it, a series of faint sparks will become visible on drawing it over its surface.

415. The source of the electricity in the pile is easily traced to chemical action; for in the lowest pair of plates in the last figure, the zinc is attacked by the fluid in the wet flannel, electric equilibrium is destroyed, the negative fluid escaping by the copper plate c to the earth, the positive being retained in the zinc. In the second couple, the negative electricity expelled by the chemical action on the second zinc plate, passes to the first zinc, and restores its electric equilibrium by combining with the positive fluid *adhering* to it; and these series of actions are repeated to the top of the pile. No greater *quantity of electricity being obtained from a pile, than from a single pair of plates;** *its tension alone being increased*, as the chemical action and disturbance of electric equilibrium, in the intermediate plates of the pile or battery, are exerted only in urging on the currents to the terminal plates; thus, as it were, increasing the momentum of the electricity evolved. The following facts will place the effects of the combinations of voltaic elements in a clearer light.

If the conducting wires of a single pair (412) terminate in zinc and copper plates, the current either traverses or refuses to pass, according to their position. Thus, in the cells A B, (fig. 226,) filled with a dilute acid, the zinc and

Fig. 226.

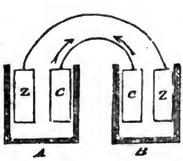
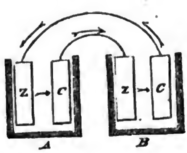


Fig. 227.

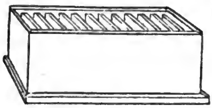


* Faraday, Phil. Trans. 1834. Exp. Researches, Series 8th, par. 991.

copper plates are mutually connected; here the current excited by the action of the acid in A on Z is opposed in direction to that similarly excited in B. The consequence is, that they mutually interfere, and no circulating force is developed. If, instead of allowing the currents in A and B to oppose each other, we cause them to pass in the same direction, (fig. 227,) we greatly increase the tension of the evolved electricity, and enable it to overcome a much greater external resistance. Thus, in the marginal figure the currents in A and B travel in the same direction, and as it were urge on each other, so that by their combined influence they can traverse a fluid which would insulate the current of A or B separately.

416. The power of the voltaic pile decreases, and finally ceases, with the neutralization and evaporation of the fluid moistening the piece of flannel, and with the oxidation of the plates. These constitute sources of considerable inconvenience in experimental investigations; to diminish which, various means have been proposed, as by fixing the pairs of zinc and copper in a trough of wood, and replacing the wet flannel by fluids poured into the cells thus formed: constituting Cruikshank's arrangement. This is very convenient, especially when a solution of sulphate of copper is used for the exciting fluid; which, as Dr. Fyfe has shown, increases the electro-chemical intensity of the electric current as compared with that evolved by dilute sulphuric acid, in the proportion of seventy-two to sixteen.

Fig. 228.

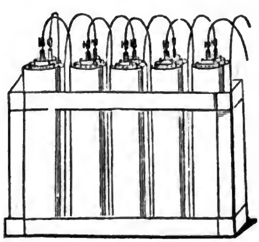


A great improvement in the construction of these batteries was effected by Dr. Wilkinson, who fixed the zinc and copper plates to a wooden beam, and immersed them when required for use in an earthenware trough, furnished with partitions of the same substance, and filled with the exciting fluid. This arrangement is rendered still more effective by causing each zinc plate to be completely surrounded by the copper plate of the next pair, as suggested by Dr. Wollaston.

Dr. Faraday has proposed an excellent arrangement,* in which the metals are brought as close to each other as possible, the alternate zinc and copper plates being separated, not by partitions of earthenware, but by pieces of stout cartridge paper or card.

417. A series of pairs constructed on Professor Daniell's principle (407), affords a most valuable source of electricity of tension, and has, moreover, the advantage of being constant in its action for several hours; whereas, the others above mentioned, although very energetic on the first immersion of the plates,

Fig. 229.

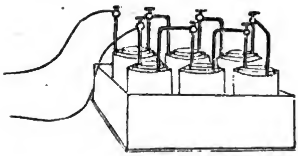


* Phil. Trans. 1835, 10th Series, Exp. Researches, 1123.

become rapidly weakened by the continual action of the fluid employed, an effect but partially prevented by amalgamating the zinc plates (397). Ten pairs on Professor Daniell's arrangement, the zinc cylinder of one being connected to the copper of the next, and so on, constitute a most valuable and powerful voltaic battery.

418. A very efficient arrangement is made by connecting in a similar manner, a dozen pairs of zinc and copper cylinders, separated by means of bladder diaphragms, the zinc being acted on by common salt, and the copper by sulphate of copper; this has the advantage of cheapness, and of being readily

Fig. 230.

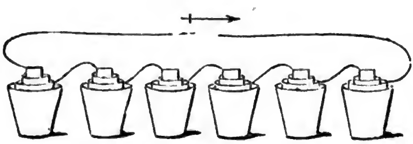


constructed. The zinc and copper plates are most conveniently connected by copper wires, fixed by a binding screw soldered to each plate, and conducting wires can be readily fixed to the screws of the terminal plates.

419. As bladders and other membranous diaphragms have the disadvantage of becoming rapidly corroded, and pierced, by the action of the exciting fluids, and of becoming torn by the sharp edges of the crystals of metallic copper deposited on the copper plate; various attempts have been made to substitute for them cylindric vessels of porous earth. Vessels of this kind have been used by Professor Daniell, and are now made sufficiently thin to prevent their opposing much obstruction to the transit of the electric current, so that their use has become extremely general. As already stated, bags of firm sail-cloth well sewn, form most excellent diaphragms, and withstand for a long time the action of acids.

420. The most powerful battery is made by an alternate series on Mr. Grove's arrangement (409). Six sets of these, each having a platina plate three inches square, placed in thin rectangular cells of porous porcelain, so as to bring them as near the zinc as possible, constitutes a most powerful and efficient arrangement. The largest hitherto constructed is that made by Prof. Jacobi of St. Petersburgh; it contains platina plates, each having a superficies of 36 square inches. Even with very small plates, a powerful battery may be made with very little expense. For this purpose procure the bowls of six tobacco pipes, and stop up the holes left by breaking off the pipes with sealing-wax. Place on the table six small glass tumblers, each an inch high, like those used by children as toys, place in each a cylinder of amal-

Fig. 234.



gamated zinc; let a pipe-bowl rest in each, and place in every one a slip of thin platinum foil 1¼ inch long and half an inch wide, connected to the zinc cylinder by platinum wire; fill the pipe-bowls with nitric acid and the tumblers with dilute sulphuric acid, and an energetic current of electricity will be set free, capable of rapidly decomposing water (434), igniting wire (427), charcoal points (423), &c.

421. It must not be supposed that all the electricity which is really excited by the chemical action of an acid or other fluid, or the generating or positive metal even in the best arrangements, really appears in the form of a current. Various causes modifying in a remarkable manner the quantity of electricity which appears in the current, exist in the best constructed apparatus. These have been mathematically investigated by Professor Ohm of Nuremburg, and the results are developed in what is known as his formula. The accuracy of this has been submitted by Professor Daniell, and in a most successful manner, to the test of experiments. The following is a brief explanation of the simple portions of Professor Ohm's investigations.

$E =$ electromotive force, equivalent to the affinity of the exciting liquid for the generating metal, and corresponding to the amount of electricity which would appear in current, if all opposing causes were removed.

$R =$ resistance opposed to E by the contents of the cell, arising for the most part from the affinity of the elements of the exciting liquid for each other.

$a =$ external resistance, arising chiefly from the imperfectly conducting nature of the wires used to convey the current.

$a =$ active force, or the amount of electricity which really reaches the end of the conducting wire.

$$a = \frac{E}{R+r}$$

The theoretical value of E is diminished materially in practice by the affinity of the conducting plate, for the ingredient of the exciting fluid which tends to combine with the generating plate; this affinity, however weak, is still seldom absolutely null. The mutual affinity of the separated elements of the fluid evolved at the surfaces of the plates also lessens the intensity of E.

The internal resistance R, varies directly with the distance D, between the two plates, and is inversely as the area of the section S of the exciting liquid. Thus, the real resistance is equal to the former divided by the latter, or

$$R = \frac{D}{S}$$

r, or the external resistance, so far as it is dependent upon the conducting wire, varies *inversely* as the square of the diameter of the wire s, and directly as its length l,* or

$$r = \frac{l}{s}$$

422. The conducting power of metallic substances differs remarkably, the worst conducting metal being many hundred times more powerful in this respect than the best conducting liquid. The following table shows the conducting powers of different metals according to Becquerel, Ohm, and Lenz.

* For the further development of this theory, and its application to series of cells, I beg to refer the student to the elaborate "Chemical Philosophy" of the late excellent Professor Daniell—a work that ought to be in the hands of every student.

	Becquerel.	Ohm.	Lenz.
Copper . .	100·	100·	100·
Gold . .	93·6	57·4	79·79
Silver . .	73·6	35·6	136·25
Zinc . .	28·5	33·3	—
Platinum . .	16·4	17·1	14·16
Iron . . .	15.8	17·4	17·74
Tin . . .	15·5	16·8	30·84
Lead . .	8·3	9·7	14·62
Mercury . .	3·45	—	—
Potassium . .	1·83	—	—

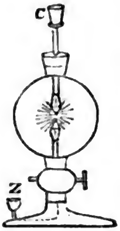
423. Let the wires connected with the terminal plates of a battery (which, if consisting of plates excited by a dilute acid (416), should consist of at least forty pairs, each being four inches square; or if the construction of Professor Daniell's arrangement, or any of its modifications, should consist at least of ten pairs, the copper plates presenting a surface of about one hundred square inches, or four or five cells of Mr. Grove's battery (420),) be connected to the two movable rods AB of the universal discharger (364), and having unscrewed the knobs, tie on each rod, by means of thin copper wire, a pencil of well burnt boxwood charcoal, or still better, of the plumbago-like substance found lining the interior of long used coal-gas retorts. On moving the rods of the discharger, so that the pieces of charcoal may lightly touch each other, a vivid light will appear between them, igniting their extremities and heating the air so intensely that on allowing the charcoal points to be drawn a little distance from each other, the discharge will continue with a most dazzling light through the intermediate portions of heated air.

If the apparatus be very small, as with a single trough on Wollaston's construction, of ten pairs of plates, a piece of the charcoal should be fixed to one of the terminal wires, and the other having a piece of platina wire fixed to its end, should be brought in contact with the carbon; at the point of contact a vivid dazzling light will be evolved, the platina wire will be ignited, and, if thin, melted into globules.

424. The discharge of the voltaic battery and consequent evolution of light, either when charcoal or metallic surfaces are employed, does not take place at first without absolute contact. Jacobi* carefully approximated two metallic points terminating the conducting wires of a battery of 12 pairs of zinc and platina plates, excited by diluted sulphuric acid, until they were within 0·00005 inch from each other, and not the slightest evidence of the passage of electricity was observed; the discharge being checked by the small interval of air. Professor Daniell† repeated this experiment with his large battery of 70 pairs, and found that no discharge ensued even on heating the closely approximated electrodes to whiteness. On transmitting the charge of an electric jar through these electrodes, so that the discharge might take place at the point of separation, the battery current became established, and luminous discharge ensued. It is evident that the discharge of the jar produced a transfer of ponderable matter from one electrode to the other, and thus formed a conducting

* Pog. Annalen. 41, 635.
† Phil. Trans. 1839, 93.

Fig. 232.



medium for the battery-current, for the luminous discharge of the battery is always accompanied by the transfer of ponderable matter.

425. The evolution of light does not depend upon the combustion of charcoal terminating the conducting wires, for it will take place with equal splendor in an air-pump vacuum. This may be shown by allowing the wire holding one of the pieces of charcoal, to slide air-tight through the brass neck of a glass globe; a second piece being fixed to a wire, fastened to the lower part, and connected with a brass cup z. On exhausting the globe of air, connecting the terminal wires of the battery with the brass cups cc, and approximating the charcoal points sufficiently, an evolution of intense and dazzling light will ensue.

These experiments are of the most brilliant kind of any in experimental science, especially when performed by the aid of a large battery, as that belonging to the Royal Institution, consisting of 2000 pairs of plates, presenting an active surface of 128,000 square inches; or of the splendid battery of 70 pairs constructed by Professor Daniell. In this case a very curious transfer of carbon from the positive to the negative side is observed, the piece of charcoal constituting the former presenting a conical cavity from this loss of substance.

426. Professor Daniell* has also observed that when the negative electrode, or the wire connected with the last zinc plate of the battery, is furnished with a termination of platinum, and the positive wire with one of charcoal; and the discharge of a powerful battery, as one of 70 alternations or transmitted, an abundance of intense light and heat is evolved, and the carbon is carried from the positive wire and deposited on the platinum point, becoming beautifully moulded to its extremity. When this arrangement in reversed, particles of platinum are transferred to the charcoal terminating the negative wire, and are deposited on its surface in the form of fused globules.

427. If the terminal wires of a voltaic battery be connected by means of a fine platina wire, and the battery be sufficiently powerful, it becomes heated to redness, and even melted. A small battery will heat a considerable quantity of wire of $\frac{1}{100}$ inch in diameter, a single pair of small plates igniting an inch; and a battery consisting of ten alternations will heat to redness about eight inches. The best mode of showing this experiment, is to roll about eighteen inches of wire into a long spiral, and place it in the interior of a glass tube; its ends passing through corks, so as to be readily twisted round the terminal wires of a battery. If the current be too weak to ignite the wire it will heat it sufficiently to communicate a very high temperature to the glass tube in which it is placed; so that phosphorus may be inflamed by bringing it in contact with its exterior. By immersing this tube in a small quantity of water, the latter may be speedily raised to the boiling point, the heat evolved by the passage of a current increases with the resistance opposed by the wire. Hence with different metals the heating power of a current traversing them will be inversely as their conducting power (367). When the conductors of a voltaic battery are terminated by their metallic wires, and the latter placed across each other; the wire terminating the positive conductor becomes ignited and melted, whilst that connected with the negative remains comparatively cool; a fact which as yet has received no satisfactory explanation. If thin metallic leaves be subjected to the action of the current of the battery, they inflame and burn with considerable brilliancy. This experiment is best per-

* Phil. Trans., 1839, p. 93.

formed by fixing a plate of polished tinned iron to one wire of the battery, and taking up a leaf of any metal, on the point of the other wire, bring it in contact with the tin plate. In this manner, gold burns with a vivid white light, silver with an emerald green, copper and tin with a pale bluish, lead with a purple, and zinc with a dazzling white flame.

428. Under certain peculiar circumstances, the passage of electricity through metallic conductors will actually *reduce*, instead of elevating their temperature. Thus, if two bars of bismuth and antimony be soldered across each other at right angles, and they be touched with the conducting wires of the battery, so that the positive electricity will have to pass from the antimony to the bismuth, the temperature of the metals will be elevated; but when the current moves in the opposite direction, viz., from the bismuth to the antimony, the metals become cooled at the point of contact. If a cavity be excavated at this point, and a drop of water previously cooled nearly to 32° be placed therein, on the current passing it will become rapidly frozen.*

429. The positive conductor, whether of a single pair, or a series, constituting the voltaic battery, is always that wire which is connected to the last *active* copper or platinum plate, and the negative that connected to the last *active* zinc. Much unnecessary confusion, with regard to the expression of the negative or positive side of the battery has been introduced in many works, from the want of a rule like that given by Faraday, of connecting their sides with a given direction of the current. Thus, in a battery constructed according to Cruikshank's arrangement (416), the positive wire or *pole*, is that which is connected to the last zinc, and the negative to the last copper plate. This difference is only apparent, as will be evident by referring to the original voltaic pile (413), when the wire from the last zinc is the positive conductor, for this reason, that the last zinc is in metallic connection with the copper plate, next to it; and hence, merely acts as a conductor from it, without adding to the power of the pile. Remove the terminal plates, and then all obscurity will vanish, for the positive electrode will be in actual contact with the last copper plate, as the intervening and *masking* plate is removed. In a Cruikshank trough, excited by an acid or saline solution, the positive electrode will be that which is fixed to the end, towards which *all the zinc plates look:* and the negative, that fixed to the end towards which *all the copper plates look.*

430. In experiments on voltaic electricity, it is necessary to make a distinction between the *quantity* and *intensity* of the electric current; the former bearing, *cæteris paribus*, a relation to the size of the plates, and the latter to the number of alternations. A pile, or other voltaic arrangement of fifty pairs excited by pump water only, will readily cause the gold leaves of the electrometer to diverge, and will produce a sensible shock; but will scarcely decompose even a small portion of water in a space of time sufficient, when the battery is excited by an acid, to rapidly resolve the same quantity into its gaseous elements (434).

431. A curious modification of the voltaic battery is found in those arrangements termed *dry piles:* these consist of a large number of alternations of some metal in a state of extreme tenuity, as silver, combined with one more oxidizable, as tin, and alternated with pieces of writing paper. The moisture in the latter substance appears to act as the exciting fluid on the most oxidizable metal. Thus, a pile composed of pieces of tin-foil and silvered paper, if containing about 200 alternations, will act powerfully on the gold-leaf electrometer by aid of the condenser. The piles of Zamboni are the most convenient: these are constructed by pasting on one side of a sheet of paper, finely laminated zinc, and covering the other side with finely powdered black oxide of

* E. Lenz, Einige Versuche im Gebiete des Galvanismus. Pog. Annal. xliv. p. 342.

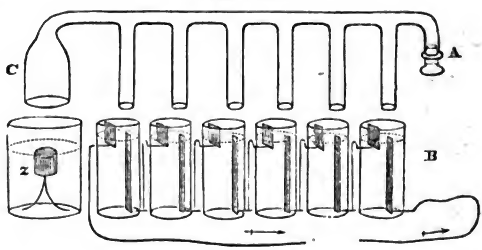
manganese. On cutting discs out of this prepared paper, and piling them upon each other, to the number of 1000, taking care to press them together, a little pile will be obtained capable of diverging the gold-leaves of the electrometer to the extent of half an inch, on touching its cap with one end of the apparatus, the other being connected with the earth. With the aid of a condenser a pile of but 300 alternations will readily act on the electrometer.

These dry piles continue in action during several years, and are capable of yielding a spark by means of the condenser, although not the faintest shock, nor the slightest evidence of chemical action has yet been obtained from them. The electricity they yield appears to be of high tension, but extremely minute in quantity, and disappears altogether when the paper discs have lost all their humidity by spontaneous evaporation.

432. A very remarkable form of apparatus for the excitation of electric currents has been invented by Professor Grove. It is termed the gas battery, and consists of a series of platina plates covered with jars of oxygen and hydrogen in the proportion to form water. It has been long shown by Faraday that plates of platina will greatly accelerate the combination of these gases. By connecting the alternate plates, Professor Grove discovered that in proportion as slow combination by the included gases went on, an extremely weak but very distinct current circulated through the apparatus, and which he succeeded in increasing in tension until it afforded a minute spark and gave distinct evidence of being able to effect chemical decomposition. A series of ten cells is sufficient to exhibit minute sparks and even slowly decompose water.

433. The following mode of constructing this curious battery is recommended by Professor Grove:—

Fig. 233.



AC is a glass tube with a series of legs attached to and opening into it. It terminates at A in an opening closed by a glass stopper and at C with a funnel-like opening. Into each of a series of glasses B, two platina plates are fixed, one long and narrow, the other shorter and wider, the former being placed lower than the latter; the wide plate of one cell is connected with the narrow one of the next by means of a platina wire. The glasses are then filled up to the top of the narrow plates with acidulated water. In the vessel Z is a piece of zinc supported on a little tripod, and is filled with dilute sulphuric acid. The stopper being removed from the tube AC, the legs are immersed in the cells so that each narrow platina plate may be inclosed in a leg, the wide ones being excluded and half exposed to the air: the hydrogen evolved in the vessel Z will rise and fill AC, expelling the atmospheric air. The glass stopper is then to be inserted into A, and the generation of hydrogen will continue until the piece of zinc becomes uncovered with acid; then the narrow

slips of platina will be exposed to an atmosphere of hydrogen in the legs of the tube, the wide ones being exposed to the oxygen of the air.* A current of electricity will thus be generated, the wire connected with the narrow plate conveying negative and that connected with the wide plate positive electricity.

CHAPTER XVI.

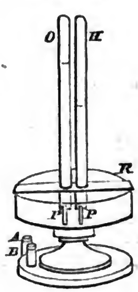
ELECTRO-LYSIS OR ELECTRO-CHEMICAL DECOMPOSITION.

Decomposition of water, 434. *Ozone*, 435. *Electrodes*, 436. *Definite nature of electro-chemical decomposition*, 438. *Electrolytes*, 439—*Positive and negative elements of*, 440. *Volta-electrometer*, 441. *Polarization of electrodes*, 442. *Electrolysis by single pairs of plates*, 444. *Apparatus for*, 445—*Reduction of metallic salts by*, 446—*Of silicon*, 450—*Of potassium and sodium*, 451—*Of ammonium*, 453. *Electrolysis by machine electricity*, 454. *Evolution of electricity during chemical combination*, 456. *Electrolysis of salts*, 458. *Professor Daniell's view of the electrolytic constitution of oxy-salts*, 459. *Resistance of chemical affinity to electrolysis*, 460. *Dr. Faraday's view of the quantity of electricity evolved during chemical decomposition*, 461.

434. HAVING learnt that the electric currents excited by chemical action may be made to circulate through conducting wires, and their force thus brought to act upon any compound body they are capable of traversing, it becomes necessary to investigate somewhat in detail the peculiarities of the change effected in compound bodies thus traversed by the currents, and study the phenomena of their electro-chemical decomposition or electro-lysis,† as Dr. Faraday has termed it.

Let the terminal wires of a battery, consisting, at least, of eight or ten pairs of plates, in good action, be placed in the cups AB, containing a few drops of mercury, and communicating with the platina plates PP. The tubes OH are filled with water rendered conducting by the addition of sulphuric acid, and inverted in the vessel E, filled with the same fluid, over the platina plates PP. Directly connection is made with the battery, the platina plates will become covered with bubbles of gas, which being evolved, will rise in the tubes OH, in unequal proportion, rather more than *twice* as much gas being collected in a given time, in one tube than in the other. This gas consists of oxygen and hydrogen, the former being evolved at the surface of the platina plate, where the current of positive electricity enters the fluid in E, and the hydrogen at that surface, where it leaves the fluid. As these gases are evolved from the decomposed water, their volumes ought to be to each other as two to one; the reason why they are not precisely in this proportion, is to be found in the partial solubility of oxygen in water; and hence, its real volume is rather less than it would be, if this source of fallacy were absent. In this experiment, the gases are evolved from both plates, simul-

Fig. 234.



* Phil. Trans. 1843.

† Ἤλεκτρον and λυω, solvo.

taneously; and, although at each instant, but a single atom of water is decomposed, the hydrogen being evolved from one, and its oxygen from the other plate, the gases are not observed to pass from P to P, the fluid between these electrodes being free from bubbles. This circumstance may be explained in a manner similar to that in which the electrolysis of hydrochloric acid has been (398); let the two platina plates be represented by the letters PN, the former being that at which positive electricity is supposed to enter, and N that which it leaves the acidulated water; ABCD are supposed to be four atoms of water lying between the plates, PN, each consisting of an atom of oxygen O, and one of hydrogen, H.

$$\text{P} \quad . \; . \; . \quad \overbrace{\text{OH}, \; \text{OH}, \; \text{OH}, \; \text{OH},}^{\text{A} \quad \text{B} \quad \text{C} \quad \text{D}} \quad . \; . \; . \quad \text{N}$$

The positive electricity entering the fluid at P, decomposes the atom of water A, with the evolution of oxygen, and causing the hydrogen to press towards N; and this being carried forward by the influence of the current, decomposes the atom B, uniting with its oxygen, and repelling its hydrogen, which, in its turn decomposes the atom C, and so on; at last, the hydrogen of the atom D is set free, and is evolved at the surface of the plate N, as the positive electricity, by whose influence the decomposition of the atoms ABCD was effected, leaves the fluid at this point. A similar explanation is applicable to other cases, in which electrolytes (439) being decomposed, the elements are evolved at distant portions of the fluid traversed by the current.

435. During the decomposition of the water by the voltaic current, a powerful phosphorus-like odor of *ozone* (331) will be evolved. The evolution of this matter, presumed generally to be a tritoxide of hydrogen, has been already noticed during the action of the common electrical machine. The odor of this *ozone* has been long recognized, but its cause was only lately traced to the formation of a peculiar compound by Professor Schönbein of Bâle. The same substance is evolved under many other circumstances, as when a stick of phosphorus is allowed to remain for a few hours in a large glass bottle full of moist air. Ozone acts on iodide of potassium, like chlorine, setting free the iodide. Hence a piece of paper moistened with a mixed solution of iodide of potassium and starch turns blue when exposed to its influence, and thus becomes an excellent test of its presence.

436. The terminations of the conducting wires of the battery, which, in the above experiment are the plates PP, constitute the points, or doors, at which the electric currents from the battery may be supposed to enter the fluid; and hence, have been aptly termed by Faraday, *electrodes;** that at which the positive electricity enters the fluid is termed the *positive*, and the other, or that by which the negative enters, is termed the *negative* electrode. The term poles, was formerly applied to these electrodes, under the supposition that they decomposed fluids by their attracting the separated elements towards them, an idea now fully proved to be incorrect, as they invariably move from one electrode to the other, under the convective influence of the passing current.

437. If, instead of platina electrodes being employed, the copper wires themselves be plunged in the dilute sulphuric acid (434), water is, as before, decomposed, hydrogen being evolved at the negative electrode; whilst at the positive the oxygen combines with the metal of which the wire is composed, forming an oxide which dissolves in the acid present.

* Ἤλεκτρον and ὁδός.
† Phil. Trans, 1834, 7th Series, 661, et sev.

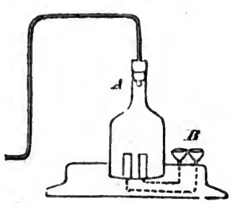
438. If several pieces of apparatus for the decomposition of water (344) be arranged, so that the current of a battery may pass through each in succession, the quantity of gases evolved in each will be found to be precisely equal. And, if the current, besides passing through one of these pieces of apparatus is made to traverse a metallic solution, as sulphate of copper; the quantity of copper precipitated in a metallic state, will bear the same relation to the quantity of oxygen and hydrogen collected, as their atomic weights do. Thus, a current of electricity capable of decomposing 9·01 grains of water will decompose 58·78 of chloride of sodium, 163·28 of acetate of lead, 79·88 of sulphate of copper, &c. This arises from the *definite nature of electro-chemical, or electrolytic decomposition*, a fact first demonstrated by Dr. Faraday.*

439. Compound bodies, capable of being decomposed by the agency of electric currents, are conveniently termed *electrolytes*.† Before an *electrolyte* can be decomposed, it is necessary that it should be capable of allowing induction, and consequent conduction to take place through it; as the latter cannot occur in the great majority of cases, whilst the electrolyte is in a solid state, it must be dissolved in water, or fused, in which state it generally readily conducts the current. Thus, the chlorides of tin, silver, and lead, are readily decomposed when the current is transmitted through them, whilst they are in a state of fusion. Some compound fluids exist which refuse to conduct the current, and therefore are not electrolytes, as a solution of pure ammonia; a few other conduct it readily, and yet can scarcely be said to yield to electrolytic force; of this class sulphuric acid is an example.

440. When various *electrolytes* are submitted in a dissolved, or fused state, to the action of the current from the voltaic battery, the *electro-negative* elements are invariably set free at the electrode where the positive current is supposed to enter the fluid; and the *positive* elements, where it leaves it. Thus, if chloride of sodium, iodide of potassium, hydrochloric acid, sulphate of copper, nitrate of lead, or fused chloride of lead, be submitted to the action of the current simultaneously, by placing them in vessels connected by platina wires dipping into each; the chlorine, iodine, sulphuric, and nitric acids will be set free at that point where the positive current enters the solutions or fused mass; whilst at the electrode where it leaves them, the soda, potassa, hydrogen, copper, and lead, will be developed in an isolated state. The evolutions of the elements of the electrolyte bearing a current relative to the direction of the currents traversing it.

441. As the only true test of the powers of a voltaic current is its *electrolytic* power, the volta-meter or volta-electrometer, as it is termed by Dr. Faraday,‡ becomes a valuable instrument in giving an approximate measure of the power of a battery, or pile. This consists of any apparatus, in which water is

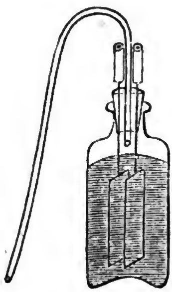
Fig. 235.



* Philosophical Transactions, 1834, 7th Series, section 7.
† ἤλεκτρον, and λυω, solvo.
‡ Philosophical Transactions, 1834, 701—741.

submitted to the action of the current, so that the gases into which it is resolved may be measured. A convenient form of this instrument consists of a glass vessel, A, cemented into a wooden base, having two plates of platina passing into its interior, connected by wires with cups or binding screws, B. The glass vessel being filled with dilute sulphuric acid, has a bent glass tube passing through a cork fixed in its mouth, so as to convey the gases evolved into a graduated receiver, standing in a pneumatic trough. A volta-electrometer may be readily constructed by fixing two pieces of thick platina-foil into a good cork, so as to dip into the interior of a small wide-mouthed bottle; wires passing from these pieces will enable them to be connected with any apparatus, and a bent tube passing through the cork will carry off the gases to be measured. The charge of these volta-electrometers should be one part of sulphuric acid diluted with eight of water.

Fig. 236.



442. The platina electrodes employed to effect the decomposition of water, assume peculiar properties, by which, on being disconnected with the battery, they develop a secondary current passing in a direction opposed to that of the battery current. This may be detected by connecting the cups B of a volta-electrometer (441), after removing the battery wire, with a delicate multiplier, the needles will immediately traverse, from the action of this secondary current. The electrodes do not lose this property entirely, by pouring out the acidulated water in which they are immersed, and replacing it by fresh, or even by washing them with hot water. If a rod of amalgamated zinc be plunged into the acidulated water contained in a volta-electrometer, whose platina plates have been previously connected with a voltaic battery for a few minutes, and wires twisted round its upper end be connected with the two cups B, decomposition of water will, of course, ensue, and hydrogen will be evolved from both platina plates, but in unequal volumes, nearly twice as much being evolved from one as from the other, as I have elsewhere shown.* This curious polarized condition of the electrodes, in all probability arises from the *fixation* of small portions of oxygen and hydrogen on their surface, a view countenanced by the experiments of Schönbein,† who has found similar properties to be assumed by platina plates after immersion in oxygen, chlorine, bromine-vapor, &c.

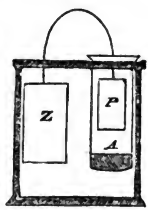
443. It is necessary for the whole electrolytic force of a voltaic current to be effectually excited, that all parts of the circuit should be formed of as good conductors as possible, as the amount of decomposition is in a ratio to the facility with which the current passes. Hence, a fluid not readily acted upon by a current in its pure state, often readily yields to its influence, when made to conduct it more readily: thus, pure water conducts badly and is decomposed with extreme slowness; on the addition of sulphuric acid it becomes an excellent conductor, and is decomposed with facility.

444. Although compound batteries have been referred to in the above remarks, as necessary to produce chemical decomposition, yet it must not be supposed that they alone are efficacious; for a single pair of plates properly constructed, is capable of effecting, by the current evolved, most important decomposing actions in bodies whose elements are held together with the greatest force. Dr. Faraday decomposed iodide of potassium (a salt capable

* Phil. Magazine, 1839. † Poggendorff. Annalen, xlvii., p. 104.

of very ready decomposition by a small force), alkaline chlorides, and sulphates, hydrochloric acid, and even water, by the aid of a single pair of plates (406). M Becquerel,* by availing himself of weak currents, aided by "affinities well chosen," succeeded in effecting the reduction not only of the more readily reducible oxides of copper, lead or tin, but even of the refractory earths glucina, alumina, and silica. This philosopher obtained these interesting results by means of a single pair of plates, placing the solution of the metallic salt in a glass tube A, closed at one end by means of a plug of moistened clay, and immersed in a weak solution of common salt: on placing a compound metallic arc formed of zinc and platinum in the solutions in such a manner that the platinum leg P might be immersed in the tube containing the metallic solution, (to which M. Becquerel applies the general term of "negative tube,") whilst the zinc dips in the solution of salt, decomposition ensues, and after a lapse of time, varying from a few hours to some weeks, the metal is generally deposited from its solution on the platinum plate in a more or less crystaline form. M. Becquerel did not attribute the reduction of the metal to the electric current alone, but conceived that three distinct causes, at least, concurred in producing this effect: the decomposition of the water and the common salt by the electric current set in motion, and the transference of hydrogen and soda through the clay diaphragm to the negative tube, where the alkali unites with the acid holding the metal in solution, causing the deposition of its oxide, which, while in its nascent state, is reduced by the hydrogen, and precipitated in its metallic form on the negative electrode; thus regarding the hydrogen furnished by the decomposition of the water as the actual reducing agent. In some cases, a fourth cause is supposed to be superadded to these, as when a body is used for the negative electrode, for which the metal in solution has a certain degree of affinity; a well-known example of which is found in the reduction of potassium from a solution of potassa when submitted to comparatively weak voltaic action in contact with mercury. Mercury is not the only metal applicable to this purpose, M. Becquerel having frequently used iron with success. He found that the solutions of the pure chlorides of zirconium, glucium, titanium, silicon, &c., refused to yield to the reducing action of weak electric currents, until after the addition of a small quantity of chloride of iron: this the current readily decomposed, precipitating the iron in a crystaline form on the platinum plate, (negative electrode,) which deposit speedily *induces* the commencement of the decomposition of the more refractory salts. This circumstance he attributes to the affinity of the iron for the other metal tending to the formation of an alloy, and expressly states, that when *perfectly pure* the above-mentioned chlorides *did not undergo the slightest decomposition.*

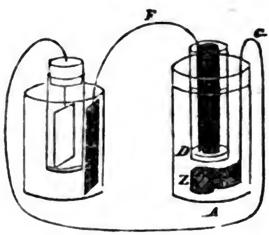
Fig. 237.



445. From a series of experiments on this subject, it appeared that the *quantity* of electricity was not so essential as a continuous weak current, and I was induced to prefer the following apparatus, (which after all is but a slight modification of Professor Daniell's,) in consequence of its affording a constant and regular current of electricity of very weak tension, continuing for several weeks or even longer without any fresh addition of exciting fluid. A glass cylinder D, 1 5 inch in diameter and 4 inches in length, was closed at one end by means of a plug of plaster of Paris 0·7 inch in thickness:† this cylin-

* Traité de l'Electricité et du Magnétisme, vol. iii. p. 228, et seq. Paris, 1835.
† Phil. Trans., 1837.

Fig. 238.



der was fixed by means of corks inside a cylindrical glass vessel A, about 8 inches deep and 2 inches in diameter. A piece of sheet copper, 6 inches long and 3 inches wide, (having a copper conducting wire F, soldered to it,) and loosely coiled up, and placed in the small cylinder with the plaster bottom: a piece of sheet zinc Z, of equal size was also loosely coiled up, and placed in the larger external cylinder (being furnished like the copper-plate with a conducting wire G). The larger cylindrical glass being then nearly filled with weak brine, and the smaller with a saturated solution of sulphate of copper, the two fluids being prevented from mixing by the plaster of Paris diaphragm, the apparatus is complete; and if care be taken that the fluids in the two cylinders are at the same level, will continue to afford a continuous current of electricity for some weeks, the sulphate of copper being very slowly decomposed.

446. If the ends of the conducting wires of this apparatus be immersed into a solution of nitrate or acetate of lead, no *immediate* action ensues, but in about fifteen minutes, or even less, some elegant and delicate feathers of metallic lead, which rapidly increase in size, appear at the negative electrode. This effect does not occur when *both* conducting wires are of platinum; but when the *negative* electrode only was composed of that metal, the reduction of the lead continued with apparently increased energy. From these experiments, as well as many others of a similar kind which it is unnecessary to detail, it appears that in availing ouselves of the *reducing* agency of feeble currents, or at least of those elicited by a single pair of plates, it is necessary that the positive electrode should be composed of a readily oxidizable metal: thus using a kind of battery of *two* cells, in which the wires forming the electrodes, and the fluid submitted to experiment, constitute the contents of the second cell.

447. But few metallic solutions yield so rapidly as those of lead to the reducing agency of weak currents: and where a longer time and continuance of action is required to effect the reduction, the decomposing apparatus of M. Becquerel will be found a necessary addition to the little battery, with the substitution of a plug of the plaster of Paris for one of clay. This piece of apparatus is, in fact, a counterpart of the battery itself, and is represented in the last figure connected to the wires FG; it consists, like it, of two glass cylinders, one within the other, the smaller one having a bottom or floor of plaster of Paris fixed into it: this smaller tube may be about half an inch wide and three inches in length, and is intended to hold the metallic solution submitted to experiment, the external tube in which it is immersed, being filled with a weak solution of common salt. Into the latter solution a slip of amalgamated zinc, (for the positive electrode,) soldered to the wire coming

from the copper-plate of the battery, is immersed, whilst for the negative electrode a slip of platina-foil, fixed to the wire from the zinc plate of the battery, passes through a cork fixed in the mouth of a smaller tube, and dips into the metallic solution it contains.

448. When a solution of the chlorides or nitrates of iron, copper, tin, zinc, bismuth, antimony, lead, or silver, is placed in the smaller tube, and connection made with the apparatus in the manner already described, action is almost instantly apparent, water is decomposed, and torrents of minute bubbles of hydrogen are evolved at the surface of the platinum plate (negative electrode), which generally continue for a short time, sometimes, indeed, lasting for hours; a circumstance depending apparently upon the degree of facility with which the metal under experiment is reduced. Thus with solutions of copper, scarcely a bubble appears, the metal being almost immediately reduced, all the hydrogen being probably employed from the instant of completing the circle, for that purpose: with solutions of lead, tin, or silver, the evolution of hydrogen continues for a short time only, and ceases as soon as the minutest portion of reduced metal appears on the platinum plate; but with solutions of iron and manganese, the evolution of gas frequently continues for six, eight, or ten hours, or even longer; the evolution of hydrogen thus seeming to bear something like an inverse ratio to the ease with which metal is reduced. After the hydrogen has ceased to appear at the negative electrode, striæ of the reduced metal, which rapidly increase, are deposited on the surface of the platinum.

The metals thus reduced generally, but not invariably, possess a perfectly metallic lustre, are always more or less crystaline, and often very beautifully so, affording a considerable contrast to the irregular soft spongy masses obtained from the same solutions by means of currents from compound batteries. The crystals of copper obtained by the process just detailed, rival in hardness and malleability the finest specimen of native copper, which they much resemble in appearance. The crystalization of bismuth, lead, and silver by these means, is very beautiful, that of the former being lamellar, of a lustre approaching to that of iron, but with the reddish tint peculiar to this metal. Silver may be thus obtained of a snowy and indeed dazzling whiteness, usually under the form of needles.

449. The metallic solutions hitherto mentioned as yielding to the action of weak currents are, as is well known, equally acted on by voltaic batteries, consisting of a considerable number of alternations, the metal being reduced in a spongy form, often destitute of a metallic appearance. But there are some metals which are deposited from their solutions as oxides only, when acted on by currents from large batteries, and yet are deposited in a brilliant metallic form if submitted to the action of the currents from the little apparatus already described. Of these nickel is an example: a solution of its chloride or sulphate, when placed in the smaller tube of the decomposing apparatus, yielding after some hours a crust of metallic nickel on the negative electrode, often of a silvery lustre on the surface immediately applied to the platinum, that portion of the crust more in contact with the fluid being generally black, and frequently covered with a layer of hydrated and gelatinous green oxide.

450. For the reduction of silicon, let a solution of fluoride of silicon in alcohol be prepared, by passing a current of the gaseous fluoride into strong alcohol. On filling the decomposing tube with this solution, and making the connection with the battery in the manner already described, bubbles of hydrogen were copiously evolved at the surface of the platinum plate (negative electrode), continuing from eight to ten hours, when the platinum appeared to be tarnished, and in twenty-four hours a copious deposit of silicon had taken

place on the platinum, to the surface of which it firmly adhered. Around the reduced silicon, and suspended in the fluid, was a dense gelatinous cloud of silicic acid. On quickly withdrawing the slip of platinum, dipping it in water, and then pressing it between folds of bibulous paper it was dried, and freed from any adhering solution. The silicon was nearly black and granular, under a lens, exhibiting a tendency to a crystaline form. It was not deposited on the platinum in a confused and irregular manner, but in longitudinal striæ, which appeared to follow the direction of certain lines of minute eminences on the surface of the piece of platinum, produced apparently by scouring it with fine sand and a piece of cork before being used for the construction of the negative electrode.

The silicon thus procured becomes of a snowy whiteness when ignited in the flame of a spirit lamp, and falls off the platinum in thin flakes, being in fact converted into silicic acid. It is not very easy to oxidate the whole, in consequence of the flakes of the acid forming an incrustation over the subjacent silicon, and protecting it from the oxidating influence of the air, even at a red heat. A portion of the silicon *removed* from the platinum did not appear to dissolve in hydrochloric acid; but when the platinum itself with the firmly adhering silicon was immersed in the acid, slow action ensued, bubbles of hydrogen being evolved from the *exposed surface of platinum*, the silicon very slowly disappearing; the solution being probably occasioned by the formation of a simple voltaic circle, the silicon and platinum being the metals, and the acid the exciting fluid. When an aqueous solution of hydrofluosilicic acid is substituted for the fluoride of silicon, the metalloid is reduced, but slower and in smaller quantity; differences arising in all probability from the smaller quantity of silicon present in the solution.

451. Potassium and sodium can be readily reduced by these weak currents and obtained as amalgams by using a modification of the decomposing apparatus before described. Let the smaller tube containing the metallic solution be replaced by a small glass funnel A, the beak of which has been carefully filled up with plaster of Paris: fix on this plaster floor a piece of glass tube closed at one end, about 0·5 inch in length and 0·2 inch in diameter, and half filled with pure mercury; this tube should not be placed vertically, but inclined so as to form an angle of about 40° with the plaster floor of the funnel. The external cylinder communicates as before with the copper plate of the battery, by means of a slip of amalgamated zinc Z, dipping into the brine it contains: a solution of chloride of potassium is to be poured into A, and a piece of platinum wire connected with the zinc plate of the battery being twisted into a flat spiral at one end so as to present a larger surface, immersed in the mercury contained in the little tube submerged in the saline contents of the funnel. The circuit being thus completed, electric action soon becomes apparent, bubbles of hydrogen being evolved from the surface of the mercury (which now formed the negative electrode) in a very curious manner, not in confused and rapid streams, but in large and distinct bubbles, which very slowly appear, and perform several gyratory movements on the surface of the fluid metal before they are evolved. Not unfrequently a single bubble only is seen, which continues playing on the surface of the mercury for half an hour, or even longer, before it rises to the surface of the fluid. In about eight or ten hours the mercury will have swollen to double its former bulk, and part of it actually crept up the platinum wire to the height of 0·3 inch above the level of the other portion, adhering to the wire like so much tenacious mucilage. This peculiar creeping

Fig. 239.

up of the mercury along the wire does not, however, take place if the little tube holding the fluid metal is placed in a vertical position. If the mercury be removed from the little tube as quickly as possible, and poured into distilled water, an evolution of hydrogen gas takes place from its whole surface, and the water becomes alkaline from the formation and solution of the oxide of potassium or potassa. The film of mercury adhering to the platinum wire remains on it for some days, giving it the appearance of having been amalgamated.

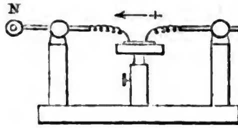
452. Of all the saline solutions that I have submitted to experiment, none afforded such conclusive and interesting results as those of ammonia; the compound *ammonium* being reduced with almost as much ease as copper or tin, when a solution of the chloride (hydrochlorate of ammonia) is submitted to the action of the voltaic current in contact with mercury, in the same maner as chloride of potassium or sodium. The same adhesion and creeping up of the mercury along the wire is observed, and after a few hours the fluid metal swells to five or six times its former bulk. On removing it quickly and drying it, by allowing it to fall on bibulous paper the amalgam of ammonium is obtained of a buttery consistence, possessing a dull silvery color, and yielding a peculiar crackling, or (if I may be allowed the expression) an emphysematous sensation to the finger on pressing it; on being immersed in water it very slowly gives off hydrogen, and yields a solution of ammonia.

453. By far the most satisfactory method of obtaining this amalgam, is by using for the negative electrode a piece of platina wire coiled up at one end, after it has been amalgamated by dipping it into the ammoniacal amalgam obtained by the last described process (452). A minute quantity of mercury is thus made to adhere to the wire, which being connected with the zinc side of the battery, is dipped into a solution of hydrochlorate of ammonia contained in the smaller tube of the apparatus used in effecting the reduction of silicon (450). The circuit being completed, a few bubbles of hydrogen are disengaged from the amalgamated wire, which soon cease, and in an hour or two, a leaden gray spongy mass is observed adhering to the wire, which is sometimes sufficiently bulky to fill the tube, and putting on much of the external appearance of a mass of cellular galena. This mass consists of a spongy amalgam of ammonium, containing a very minute proportion of mercury; it is lighter than the solution in which it is immersed, for on adroitly separating a portion of it, it rises to the surface and rapidly decomposes water, hydrogen being evolved and ammonia formed.

It is a very curious and interesting fact, that although this spongy ammoniacal amalgam cannot be kept immersed in water even for a few instants without the formation of ammonia, yet as long as it is connected with the negative electrode of the battery, it may be preserved without change for days and weeks. The instant the connection with the battery is broken, a mass of this amalgam, as large as a walnut, appears to vanish in a few seconds, torrents of minute bubbles being given off, and a scarcely appreciable quantity of mercury being left on the wire. On again closing the connection with the battery, decomposition recommences, and the amalgam is reproduced.

454. Decomposition of several electrolytes, as sulphate of soda, iodide of potassium, &c., may be effected by means of a current of electricity, from the ordinary electrical machine. For this purpose, place upon the table of the universal discharger a piece of bibulous paper, soaked in a solution of some alkaline combination, as iodide of potassium; fix to each of the sliding rods of the apparatus a piece of fine platina wire, to serve as electrodes, which must rest lightly upon the paper, about an inch from each other. Connect one of the rods N with the rubber of the machine, or with the earth by means of a chain, and the other P with the prime conductor by a wire, or still better,

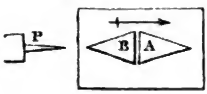
Fig. 240.



by a piece of wet string; on working the machine, the salt will be decomposed: iodine being set free at that wire which is connected with the conductor, or at the point where the positive electricity enters the compound, and the alkaline base at that which is connected with the rubber, or where the positive current escapes. The alkaline element can be detected by placing a piece of turmeric paper, moistened, with the solution employed, on the table of the discharger, in place of the ordinary bibulous paper.

455. It is not necessary to use metallic conductors to effect electro-lysis by the electricity of tension. To show this, take two triangular pieces of paper A B. B being colored with litmus, and A with turmeric, place them base to base on a glass plate and moisten them with a solution of sulphate of soda, let a pointed wire fixed to the positive conductor P of an electrical machine in action be placed a few inches from B, the sulphate of soda will be decomposed, the acid set free at B, where the electricity enters the paper, and will turn its blue color to red, whilst the soda will be set free at A, staining it brown. This elegant experiment of Prof. Faraday is conclusive against the old notions of the electrodes inducing decomposition by acting as attracting surfaces or poles.

Fig. 241.



456. Electricity is not only evolved during chemical decomposition, but has been supposed to attend *chemical combination;* a statement first made by Becquerel. The truth of this opinion has been, by many, either altogether denied, or limited to the case of the combination of nitric acid with alkalies. That an electric current, certainly of extremely low tension, is readily evolved *during* the combination of sulphuric, hydrochloric, nitric, phosphoric, and acetic acids, with the fixed alkalies, and even with ammonia. is readily demonstrable, but what the immediate cause of this evolution of electricity may be, is questionable. In the case of electricity evolved during the combination of nitric acid and potassa, or Becquerel's battery, as it is termed, Prof. Daniell's view of the composition of salts enables a tolerably ready explanation to be applied. This apparatus consists of a tube closed by a plug of pipe-clay filled with a solution of potass, and immersed in a vessel of nitric acid. Plates of platina furnished with conducting wires are immersed in the acid and alkali. As soon as these conducting wires are twisted together an electric current takes place, oxygen rising in bubbles from the plate immersed in the alkali, whilst hydrogen is evolved in the acid and immediately acts on it, tinging it yellow from the formation of nitrous acid, the hydrogen abstracting a portion of oxygen from the nitric acid. Meanwhile combination of the acid and alkali occurs through the clay diaphragm, and nitrate of potassa is slowly formed.

On Prof. Daniell's hypothesis, nitrate of potass, considered in its electric relations, is a compound of

$$\left.\begin{array}{l}\text{1 atom nitrogen}\\ \text{6 —— oxygen}\end{array}\right\} + \text{1 atom potassium;}$$

and not of

$$\left.\begin{array}{l}1\text{ atom nitrogen}\\5\text{ —— oxygen}\end{array}\right\} + \left\{\begin{array}{l}1\text{ atom potassium}\\1\text{ —— oxygen;}\end{array}\right.$$

and hence nitre on this view is termed *oxynitrion of potassium.* Aqueous nitric acid will therefore be an oxynitrion of hydrogen, thus constituted:

$$\left.\begin{array}{l}1\text{ atom nitrogen}\\6\text{ —— oxygen}\end{array}\right\} + 1\text{ atom hydrogen;}$$

and not as usually assumed, of

$$\left.\begin{array}{l}1\text{ atom nitrogen}\\5\text{ —— oxygen}\end{array}\right\} + \left\{\begin{array}{l}1\text{ atom hydrogen}\\1\text{ —— oxygen}\end{array}\right\} = 1\text{ atom water.}$$

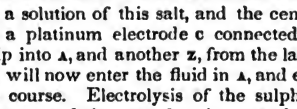
In Becquerel's apparatus, the following elements are therefore arranged on each side the porous diaphragm, represented below by the double horizontal line.

$$\begin{array}{l}1\text{ Oxygen}\\ \left.\begin{array}{l}1\text{ Potassium} \ldots\ldots\ldots\\ \hline\hline 1\text{ Nitrogen} \ldots\ldots\ldots\\ 6\text{ Oxygen} \ldots\ldots\ldots\end{array}\right\} = \begin{array}{l}\text{Oxynitrion of potassium}\\ \text{or nitrate of potassa.}\end{array}\\ 1\text{ Hydrogen}\end{array}$$

Thus, an atom of oxygen is set free in the alkaline solution, and one of hydrogen in the acid, so that in this case the evolution of electricity may be readily traced to chemical decomposition; consequently Becquerel's arrangement does not represent any exception to the general rule.

457. The statement, that in cases of electro-chemical decomposition, the changes which take place in the electrolyte are continuous through a line of molecules, and not limited to those in contact with the electrodes (334), meets with an interesting illustration in the well-known experiment in which an alkali appears to traverse an acid without combining with it; and which has been erroneously regarded as a case of suspension of the laws of chemical

Fig. 242.



affinity. Let three cups A S B, be placed side by side, and connected by means of pieces of lamp-cotton moistened with a solution of sulphate of soda. Let A and B be filled with a solution of this salt, and the central cup S, with dilute sulphuric acid. Let a platinum electrode C connected with the last copper cell of the battery, dip into A, and another Z, from the last zinc plate dip into B. The positive current will now enter the fluid in A, and escape from B through Z, traversing S in its course. Electrolysis of the sulphate of soda will take place, its acid with oxygen being set free in A, and the sodium will pass through the sulphuric acid in S and reach B, so that a quantity of free soda will soon be found in B; the sodium being oxidized at the expense of the water. It is evident that this alkaline body must have traversed the acid in S, with which, indeed, it for an instant combined, and the resulting sulphate of soda being decomposed by the current, the soda ultimately appears in B.

458. That in experiments of this kind, the base really combines with the acid it is made to traverse, is proved by using a salt with the base of which

the acid forms an insoluble combination. Under these circumstances it is removed from the influence of the current, and does not reach the third cup. Place in A B solutions of chloride of barium, and in B dilute sulphuric acid; on the current passing, the contents of A are decomposed, chlorine is evolved, and barium set free; this is conveyed in the manner before described to the middle cup, and here it is arrested in its course by the acid which, in combining with it, forms an absolutely insoluble salt, the sulphate of barytes, which falls to the bottom of the vessel, and then neither barium nor its oxide reaches the cup D. Hence the salt chosen for experiment must be one whose base forms a soluble combination with the acid in the middle cup (457).

459. When water containing a very minute proportion of saline matter is subjected, in two cups connected by threads of moistened lamp cotton, to the action of the current, not only are the elements of the water set free, but the traces of saline matter are decomposed into their constituents, so that the acid will appear in one cup and the base in the other. It has been observed by Professor Daniell, that if a solution of sulphate of soda be thus treated, a volta-electrometer being included in the circuit, not only is the quantity of mixed gases collected in the latter the same in bulk as that set free in the sulphate of soda solution, as we should expect (438); but a quantity of the sulphate is itself decomposed, equivalent to the gaseous elements evolved from the decomposition of water in the volta-electrometer and in the solution of the sulphate. Thus, the current which decomposed an atom of water in the volta-electrometer, at the same time decomposed an atom of water and one of sulphate of soda in the apparatus connected with it; forming an apparent exception to the general law (438). To meet this difficulty, Professor Daniell has suggested that the elements of the water in which the salt is deposited, are separated by a secondary action. According to this view, sulphate of soda consists of $SO_4 + N$, instead of $SO_3 + NO$, being in the proposed nomenclature an oxysulphion of sodium. Then, when a solution of this salt is decomposed by an electric current, SO_4 is set free, and immediately acts on the water, taking an atom of hydrogen to form the aqueo-acid, and thus an atom of oxygen is evolved from the water. The sodium then acts on another atom of water to form soda with its oxygen, and setting free hydrogen, and thus the decomposition of an atom of water and one of sulphate of soda by a current, which is alone capable of decomposing one atom of water when the salt is absent, is attributable to the secondary action of the assumed elements of the salt on the water. The same ingenious explanation applies to the electrolysis of all solutions of oxy salts.

460. It has been already observed that salts materially differ in the facility with which their elements are evolved under the influence of the electric current. This difference is attributable to the varying amount of intensity with which their elements are united. Thus, as has already been shown, the current from a single pair of platinum and zinc plates is capable of decomposing a solution of iodide of potassium; chloride of silver kept fused in a glass capsule is readily resolved into chlorine and metallic silver by the same weak current. On the other hand, a solution of sulphate of soda and nitrate of potass in a state of fusion, resist the action of this current, but if its intensity be exalted by the addition of a little nitric acid to the exciting liquid, it is capable of overcoming the force which ties the elements of these salts together, and they are readily evolved at the surface of the respective electrodes. In the following list of electrolytes, the first three are decomposed by the current from a single pair excited by dilute sulphuric acid, while the last four bodies do not yield until after the addition of nitric acid to the exciting liquor.

Iodide potassium, dissolved in water.
Chloride of silver, fused.

Protochloride tin, fused.
Chloride lead, do.
Iodide lead, do.
Hydrochloric acid.
Dilute sulphuric acid.

461. The essential difference between the electricity of the common electric machine and that evolved by chemical action, consists in the low tension or elasticity of the latter, as compared with the former, which it vastly exceeds in quantity. By availing himself of the law of the definite nature of electro-chemical decomposition, Dr. Faraday has, by a series of very ingenious experiments, succeeded in demonstrating the enormous quantity of electricity naturally associated with the elements of a grain of water. He found that when two wires of platinum and zinc $\frac{1}{18}$ inch in diameter were immersed to the depth of $\frac{5}{8}$ of an inch in a mixture of one drop of sulphuric acid and four ounces of water, as much electricity was set free by this miniature battery in about three seconds of time, as was yielded by an electric battery (297) having 3,500 square inches of coated surface, and charged by thirty revolutions of a plate-glass machine 50 inches in diameter. The quantity of electricity in the state of tension yielded by the machine, and sufficient to kill a small animal, was thus evolved by the solution of an almost inappreciable portion of zinc wire. By an extension of this reasoning, it would appear that 800,000 charges of the electric battery would be required to decompose a grain of water, a quantity capable of being supplied in an infinitely lower state of tension by a pair of platinum and zinc plates, sufficiently excited by an acid to keep ignited during rather less than four minutes, a platinum wire $\frac{1}{104}$ inch in diameter.

NOTE.

To the no less excellent than laborious Traité de l'Electricité et du Magnétisme, of Becquerel, I beg to refer the student for an elaborate account of all that is valuable in electrical science; especially, in that interesting part of the science connected with the application of electricity to chemistry, contained, chiefly, in the third volume. For an abstract of this in an English dress, I would also refer to the excellent scientific Memoirs of Mr. Richard Taylor, pp. 414–42. The papers of Dr. Faraday, in the Philosophical Transactions, now fortunately collected into a separate work, cannot be too frequently or too attentively perused by those who wish to acquire a thorough acquaintance with this beautiful science. Nor ought the writings of Pouillet, Coulomb, Poisson, De la Rive, and many other continental philosophers, as well as those of our talented countryman, Prof. Daniell, to be overlooked by the student. An authentic perusal of Section VI of Muller's Physics will also amply repay the student, by the able exposition there given of the subject.

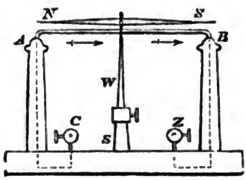
CHAPTER XVII.

ELECTRO-DYNAMICS.

462. The direct influence of the discharge of electricity of tension, on magnetic needles, was studied long ago by Franklin, Beccaria, Wilson, Cavallo, and others; the power it exerted of destroying, reversing, or communicating polarity was also pointed out. But it was reserved for Prof. Oersted, of Copenhagen, to announce to the world the existence of a new and peculiar force reciprocally exerted between magnetic bars, and the connecting wires of a voltaic battery; a fact, to a certain extent, theoretically anticipated in a work, by the same philosopher, published twenty years before his great discovery, which was made in 1820.

463. Let a copper wire, connected with the two sides of a voltaic arrangement, be stretched parallel to a magnetic needle, supported on a pivot, and on a plane just above it. The magnet will instantly leave its position in the magnetic meridian, and after a few oscillations will assume, and retain, a position at, or approaching to, right angles to the wire, as long as the current continues to pass. To show this, let a thick brass wire be supported by two pillars AB, passing through their long axes, and soldered to the binding screws

Fig. 243.



CZ. The magnetic needle NS is supported by a pointed wire W, fixed in a hollow stem S, in which it may be placed at any height by means of a screw. N is the austral and S the boreal pole of the needle (258): the former being what is commonly termed the north, and the latter the south pole.

(A.) Screw the wire coming from the copper plate of an electromotor (400) into C, and that from the zinc into Z, the positive current will pass in the direction AB, as shown by the arrows; and the needle NS, placed in the mag-

netic meridian, will move from its previous position, its end N, moving towards the *west*.

(B.) Lower the wire W into the socket S, so that the needle NS may be *beneath* the conducting wire. On making connection with the electromotor as before, the end N of the needle moves towards the *east*.

(C.) Remove the wire W and the magnetic needle, replacing it with one arranged as a dipping needle, parallel to, and on the same horizontal plane with the conducting wire AB. On making connection with the electromotor (A), the end N of the needle will be *elevated*, providing its poles be in the same position as before, and it be placed on the *west* side of the wire AB.

(D.) Arrange the apparatus as before (C), but let the dipping needle be placed on the *east* side of AB; its poles retaining their former direction. The pole N will then be depressed.

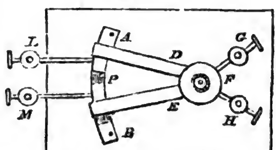
If these experiments be repeated, the connection with the electromotor be reversed, so that its copper plate may be connected with the screw Z, and its zinc with the screw C, the direction of the magnetic deviations will also be reversed.

464. To impresss on the memory the directions of these deviations, the following formula devised by Ampere is extremely useful: *let any one identify himself with the current, or let him suppose himself to be lying in the direction of the positive current, his head representing the copper and his feet the zinc plate, and looking at the needle, its north pole will always move towards the right hand.* This will be readily apparent if the student will suppose himself to be lying on the wire A B (463), in the direction of the positive current and looking towards NS, and then repeat the above experiments.

465. The amount of action exerted on the magnetic needle by the electric current, appears from the researches of Biot and Savart* to diminish with their mutual distance, its intensity being in the inverse ratio of the square of the distance of the needle from the wire, *when considered as applying to a small section of the conducting wire;* and of course proportional to the sines of the angles of deviation. But as the length of the current may be considered to be infinite with regard to the needle, its intensity is in the inverse ratio of the simple distance, when considered as being exerted by an indefinitely long conducting wire.

466. To avoid the trouble and difficulty of reversing the direction of the battery current in electro-magnetic experiments, several pieces of apparatus have been contrived, most of which are very inconvenient, from their requireing mercury to fit them for use. I have had an instrument constructed, which when used to connect the battery with any apparatus, allows the direction of the current to be readily changed without using that fluid metal. This consists of an elevated curved ridge, composed of three stout pieces of brass, A PB, separated as in the figure at the dark portions by wood; A and B communicate by means of a thick wire passing under the base of the instrument. Two thick quadrangular bars of brass, DE, pass through a circular piece of wood, F, and terminate in the binding screws GH. The bars DE, and the piece F moving with it as on a centre, being made to press upon the curved ridge AB by means of a screw at F. Two other binding screws, LM, are connected to A and P. If the bars be placed as in the figure, the copper plate

Fig. 244.



* Précis de Physique, par M. Biot, tom. ii. p. 707. Paris, 1824.

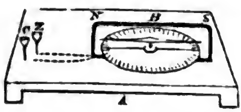
of a battery being connected to G, and the zinc to H, the positive current will flow from L to M if they be connected by means of a wire or any piece of apparatus. Let the bars be then moved until the end of E rests on B, D will of course be on F, and instantly the positive current will move in the opposite direction, or from M to L.

When this instrument, which I propose to call the *inversor*, is used, a drop of oil should be placed on AFB, to allow DE to glide readily over it.

467. From a consideration of the above experiment, it is obvious that if a conducting wire be bent into the shape of a rectangle, the needle being placed between its two horizontal branches, the action of a current traversing the wire will be, to move the needle in the *same* direction; for although one branch is above, and the other below the needle, yet as the current moves in each in opposite directions, its effects on the magnet will be the same.

In this manner we possess a mode of increasing the action of a current on the needle to an extraordinary degree, and acquiring a mode of detecting traces of electricity infinitely too minute to act on the gold-leaf electrometer. For these valuable contrivances we are indebted to the ingenuity of Schweigger. The commonest form of these instruments, galvanometers or multipliers, as they are termed, consists of a rectangular coil of copper wire NBS, containing about twenty convolutions, the wire being covered with cotton or silk, to prevent the lateral escape of the current. The cups CZ are connected, repectively, to an end of the wire coil, NBS. A magnetic needle, supported on a pivot, is placed in the centre of the coil, and a card, graduated into 360°, is fixed to the board A on which the coil rests, so that a line drawn from 360° to 180° coincides with its long axis. On connecting any source of feeble electricity to the cups ZC, the current will traverse the coil, and the needle will move to the east or west, according to the direction of the electricity (464).

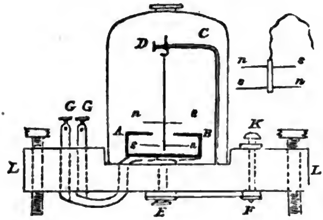
Fig. 245.



468. This form of multiplier will, it is obvious, detect the existence of a current only when it is sufficiently intense to overcome the directive action of the earth, which tends to retain the needle in the magnetic meridian. If the current be too feeble to produce this effect, its existence cannot be detected without using a much more delicate instrument. To the late Chevalier Nobili, we are indebted for the application of the *astatic* needle to the multiplier, thus enabling us to detect the existence of currents of the lowest tension, by annulling the directive action of the earth on the needle. The following is a description of one of the many forms of multipliers that have been proposed, and which I prefer on account of its extreme sensibility, and the facility with which it is used:—

It consists of a firm base of mahogany, LL, excavated in the centre, and supported by four levelling screws, of which two are shown in the section. The coil AB is formed of copper wire one sixtieth of an inch in thickness, and about two hundred feet in length, carefully covered with cotton to prevent lateral contact. This wire is wound on a thin wooden frame two inches *square*, the upper and lower portions of which are about one inch apart; this frame is fixed to a circular piece of wood passing through the board LL, and ending in the grooved wheel E, connected by means of a piece of cord with the pulley F, moved by the handle K, so that when the latter is turned, the frame and coil AB are moved round their vertical axes. The ends of the coil, after being twisted into a loose spiral, pass through the board, and are soldered to the binding screws GG. The magnetic needles are thin, light sewing needles, about one inch and a half in length, possessing very nearly

Fig. 246.



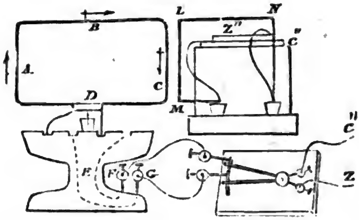
the same degree of magnetic intensity, and fixed about three quarters of an inch apart, on a piece of straw or wire, as shown in the small figure, with their poles opposed in direction. The piece of straw is placed in the vertical axis of the coil, so that the lower needle may be between, and the upper one above the convolutions of wire; the whole system being supported by means of a filament of unspun silk, or fine human hair, from the arm C, being readily raised or depressed by means of the screw D. A circular piece of card graduated into 360°, is placed on AB, and before the instrument is used, the folds of wire on the frame should be placed exactly parallel to the needles by moving K. A glass shade is placed over the apparatus to prevent any disturbance ensuing from currents of air. If any source of an electric current be connected to the screws GG, the needles will immediately deviate from their previous position, the intensity of the current being, in general, as the sine of the angle of deviation, especially as the needles used always possess some slight directive power. To illustrate the delicacy of this instrument, place on the top of one of the brass screws GG, a drop of spring water, and having a piece of zinc connected to the other screw, immerse its extremity in the drop of water, the needles will immediately be moved by the weak current thus excited. The multiplier constitutes one of the most valuable instruments in electro-chemical researches that we are acquainted with.

469. As all action is attended by its corresponding reaction (61), if in any of the experiments described, the magnets be fixed, and the conducting wires movable, thus reversing the conditions of the experiment; the wires will be acted upon by the magnets, and assume a constant position with regard to the direction of the current, and position of the magnetic poles.

470. Let a thick curved wire be connected to an electromotor so that the current may traverse it; divide it in the middle, leaving about an inch between the divided portions, and re-connect them by means of a piece of fine copper wire. On dipping this thin wire, whilst the current is passing through it, into iron filings, they will be attracted and adhere to it as if it had suddenly acquired magnetic properties. The filings will be attached to the wire in the form of rings, about one-twentieth of an inch apart, and will drop off the instant the current ceases to pass.

471. Wires conducting electric currents, *if free to move, attract each other when the currents are moving in the same, and repel each other when moving in the reverse direction.* To show this, let a frame, ABC, of copper wire be fixed to a piece of light wood, moving on a pivot, the ends of the wire dipping into two concentric cells, filled with mercury, and connected by wires passing through the stem E to the screws FG. These screws are connected by wires to the *inversor* (466), which by the wires C′Z is itself communicated to the two plates of an electromotor. A current thus traverses the frame ABC, in a direction

Fig. 247.

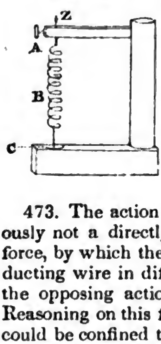


varying with the position of the bars of the inversor. Let us suppose that the current of positive electricity moves in the direction shown by the arrows.

Place a thick curved wire, LN, in communication by means of cups of mercury, with the two plates z''c'', of a small electromotor. Approach this wire towards C; the positive currents will be descending both in C and in LM, and thus moving in the *same* direction, the frame of ABC will move on its centre to meet LM, mutual *attraction* ensuing. Then move the bars of the *inversor*, so that the positive current will ascend in C, instead of descending, and immediate *repulsion* will occur.

472. By means of Roget's electrical spiral, the mutual attraction of conducting wires conveying currents moving in the same direction can be easily demonstrated. This consists of a loose coil of thin copper wire AB, suspended from a metallic support Z, connected with one plate of a battery. The end B just touches the surface of some mercury communicating by the wire C with the other plate. On establishing connection with the battery the wire coil will rapidly vibrate longitudinally (86), the coils approaching each other; the connection with the battery is thus broken. The weight of the wire causes it to fall into the mercury again, and the passage of the current is restored.

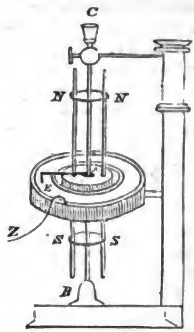
Fig. 248.



473. The action exerted by a conducting wire on a magnet (463), is obviously not a directly attractive or repulsive one; but is rather a tangential force, by which the opposite poles of the magnet tend to rotate round the conducting wire in different directions, and assume a state of equilibrium when the opposing actions of the wire on both poles become equally balanced. Reasoning on this fact, Dr. Faraday concluded, that if the action of the current could be confined to one pole only of the needle, a rotatory motion, providing no opposing forces interfered, might be produced. After a series of experiments on this subject, he succeeded perfectly, and thus developed one of the most interesting and extraordinary phenomena in electrical science.

The most convenient apparatus for illustrating the rotation of magnets round a conducting wire, consists of two slender magnets, NS, NS, fixed equidistantly from each other, with their poles in the same position, in the piece of wood A, supported by a pointed wire B, so as to move readily on its centre. The middle of the piece of wood A, is excavated, and contains a drop of mercury, which communicates by means of a curved wire dipping into it, with the external circular trough of mercury E. A pointed copper wire, supported by a screw at C, dips into the mercury in A; and is furnished at its upper end with a cup containing mercury, so as to be readily connected with an elec-

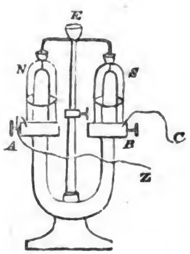
Fig. 249.



tromotor, by means of the *inversor* (466). The cup C and trough E are then connected, the former with the copper, the latter with the zinc plate of the electromotor. So that the positive current *descends* from C to A, and then reaching E through the curved wire, escapes to Z. It thus acts only on the poles NN of the magnets, which if austral poles, will immediately begin to rotate round the conducting wire C, from left to right, or in a direction like that of the hands of a watch. By turning the bars of the *inversor*, or otherwise changing the direction of the current, the direction of the rotation will immediately become altered. The same thing also occurs, when the position of the poles of the magnets are reversed. Let the magnets or currents be arranged as they may, the direction of the rotation always corresponds to the formula of Ampere (464). It may here be remarked, that in this as in all other experiments in electro-magnetism where wires dip into mercury, their ends should be cleaned and *amalgamated*, by being dipped into a solution of nitrate of mercury to ensure perfect contact.

474. In accordance with the law of equality of action and reaction, if the magnets be fixed and the conducting wires movable, the latter will readily rotate round the former. This may be very easily shown by means of the horse-shoe magnet NS, placed in a vertical position, with circular troughs AB,

Fig. 250.



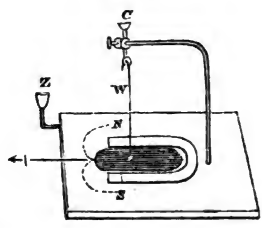
screwed upon its legs; a light wire frame supported by a fine steel point from each pole of the magnet, is so arranged that its vertical branches just touch the surface of the mercury in AB. Each of the wire frames terminates in a cup containing a drop of mercury, into which the ends of the cross wires from E dip. Connect the cup of mercury E, by means of a wire, with the copper plate of the electromotor, either directly or by means of the *inversor*, and let the wires CZ, coming from the circular troughs AB, be *both* connected with the zinc plate of the apparatus. Under these circumstances a current of positive electricity will pass from the copper plate to the cup E, and there being divided into two portions will descend the vertical branches of the wire frame, and reach the troughs AB, leaving the apparatus by the wires CZ. Directly the current is in motion, the wire frame suspended to the north pole of the magnet begins to rotate rapidly in a direction from left to right, and that round the south pole, in a contrary direction, from the *reaction* of the fixed magnet on

the movable conducting wires. If the direction of the current be reversed, either by altering the connections with the electromotor, or by shifting the bars of the inversor, the direction of the rotation will also become reversed.

475. The rotation of a conducting wire may be also conveniently shown, by bending two wires into heliacal coils like corkscrews, and allowing each to rest by one extremity on the depression on each pole of the horse-shoe magnet (474), the other end dipping into the mercury in the circular troughs A B. On connecting one of the latter with the zinc, and the other with the copper plate of the electromotor, the current will ascend through one helix, descend the pole of the magnet which supports it up the other pole, and reaching the second helix will descend along it; and thus by the mercurial trough into which it dips, reach the zinc plate of the exciting apparatus. In this variation of the experiment, the heliacal coils of wire will rotate round either pole *in the same direction*, because whilst the positive current ascends in one, it descends in the other.

476. If, instead of submitting a conducting wire to the action of one magnetic pole only, it be so arranged as to be exposed to the influence of both poles, a vibrating, instead of a rotatory, motion ensues. Let a light wire, W, suspended from a brass rod connected with the cup of mercury, C, so that its lower end just dips into a cavity cut out in the base of the instrument, filled with mercury, be connected by a wire with the cup Z. Let a horse-shoe magnet be

Fig. 251.

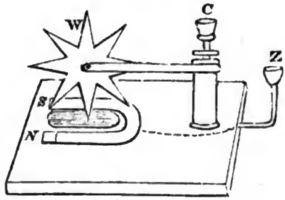


placed, as shown in the figure, and connect C with the copper, and Z with the zinc plate of an electromotor; the current of positive electricity will descend W, and being acted upon by both poles of the magnet, the wire will tend to rotate to the right, round the *austral* pole, N, and to the left, round the *boreal* pole, S. As it cannot at once obey both these forces, opposed in direction, it takes an intermediate course, as would be expected, from the law of composition of forces (64), and is thrown forwards out of the mercury, in the direction indicated by the arrow. Connection being thus broken with the battery, the wire, by its gravity, falls into the mercury, and is again thrown out, keeping up this pendulum-like motion for a long time. Let the direction of the positive current be changed, or the position of the magnet be reversed, and a vibrating motion of the wire, in an opposite direction, or backwards, will ensue.

477. If the electric current be made to pass through a spur wheel, W, instead of a wire, a rotary movement between the poles of the magnet ensues. Thus, if the positive current passes from the cup C to the axis of the wheel W, it descends through that spoke which happens to dip into the mercury, and passes from thence to Z, and to the zinc plate of the electromotor. As soon as the current descends the radius of the wheel, the portion dipping into the

mercury is thrown out, as in the vibrating wire; another spoke of the wheel dips into the mercury, and is thrown out in its turn, and so on, a continual

Fig. 252.



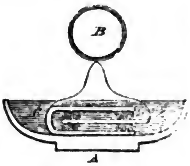
rotatory motion ensuing. If the direction of the poles of the magnet, or of the electric current, be reversed, the wheel will still rotate, but in an opposite direction. The wheel W may be replaced by an entire disc of metal with advantage, as the motion is then more uniform and continued.

478. If a horse-shoe magnet be approached to a suspended rectangle of wire, through whose sides an electric current is passing (471, A, B, C, D), it will be forcibly attracted, whilst the current is passing, and the poles of the magnet placed in one direction; and repelled, if either of these positions be reversed. This apparent attraction is really owing to the same cause which determines the vibration of a wire suspended freely between the poles of a magnet (474). The rectangle having a tendency to rotate, in common with all conducting wires (474), round the poles of the magnet, in opposite directions, it is compelled, by the law of composition of forces, to advance between, or move from, these poles, according to the positions in which they are respectively placed.

479. If the freely suspended rectangle before described, through which an electric current is moving, be left to itself, uninfluenced by any opposing cause, it will be acted upon by the magnetism of the earth, and will assume a definite position; which it will, if sufficiently mobile, regain, when disturbed from it by any applied force. That *face* of the rectangle through which the positive current is moving in the direction of the hands of a watch, always turning towards the south, whilst the other, or that in which the current of positive electricity appears to move from right to left, or opposed to the hands of a watch, will assume the properties of an austral pole, and will consequently point to the northern hemisphere of the earth. Thus in the figure referred to (471), that face of the rectangle ABC, which is there represented, will regard the south pole of the earth; the current of positive electricity moving in it from left to right. If the conducting wire be bent into a circular or other figure, it will present the same phenomena as the rectangle; the shape not influencing its properties.

480. If, instead of using a single fold of wire, as a circle, or rectangle, several convolutions be employed, its polar phenomena will be proportionably increased. This may be very satisfactorily shown by means of the little apparatus contrived by De la Rive, consisting of a plate of zinc, Z, about an inch square, placed between the folds of a bent plate of copper of the same size. A piece of copper wire, covered with silk, is soldered to the copper plate, and after being twisted into about twenty circular coils, B, kept close together by means of thread, is fixed by its other extremity to the zinc plate.

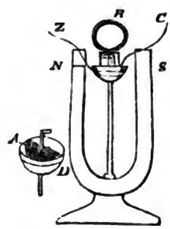
Fig. 253.



This apparatus is placed in a shallow wooden cup, A, filled with diluted sulphuric acid, and, on allowing it to float in a vessel of water, the whole will, after a few oscillations, arrange itself in the magnetic meridian. The action of the acid on the plates CZ developing sufficient electricity to cause the coil B to present magnetic phenomena: that aspect, in which the positive current appears to be moving from left to right, regarding the southern hemisphere of the earth. On presenting a magnet towards the coil of wire B, whilst the apparatus is in action, attraction and repulsion will ensue, as if the wire itself had really become a magnet.

481. The peculiar polar properties of this coil of wire may be beautifully shown by fixing it on a pivot, in the centre of a shallow circular trough of mercury, divided into two portions by a little wooden partition, as shown at AD. The ends of the wire coil are pointed, and so long as just to touch the surface of the mercury in the divided box AD, as it, by capillary repulsion (31),

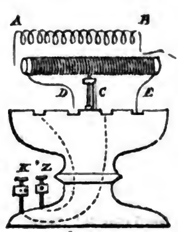
Fig. 254.



rises above the level of the partition without overflowing. On connecting the two cells of mercury, by means of the wires, CZ, with the two plates of an electromotor, and placing the whole between the poles of a horse-shoe magnet, the wire coil, B, will revolve rapidly, from the two faces of the coil being alternately attracted and repelled by the magnetic poles NS, and the direction of the current traversing it being reversed at each half revolution.

482. The coil of wire used in the preceding experiments may be regarded, as long as the current traverses it, as a *flat* magnet; but if the convolutions,

Fig. 255.



instead of being nearly in the same plane, be drawn out, so as to represent a long helix, as AB, its apparent magnetic properties become much more distinct. Let a wire, covered with cotton or silk, be coiled on a glass tube, in a direction from left to right, forming a right-handed helix, and be supported on a pivot, as at C, its two ends, DE, hanging down, and just dipping into two concentric troughs of mercury, connected with the screws, KZ, as in the support of the rectangular conductor before described (471). On connecting these screws with the two plates of an electromotor, the electricity will traverse the heliacal conducting wire, which, after a few oscillations, will arrange itself in the magnetic meridian; that end in which the positive current moves from left to right, pointing towards the south pole of the earth. The two extremities of this helix are respectively attracted or repelled by the poles of a magnet, as long as the electric current traverses it, as completely as if it were a permanent steel magnet. Ampere, to whom we are indebted for the knowledge of the properties of this and other heliacal conductors, has termed it the *electro-dynamic cylinder*.

483. The most interesting property of this heliacal conductor, is its power of inducting actual magnetism in a bar of soft iron, placed in its interior. Thus, if a bar of soft iron, in which magnetism is readily excited, be placed in the helix AB (482), and a current of electricity be made to pass through the latter, by connecting its two extremities with the plates of an electromotor, the bar of iron will instantly acquire the power of attracting another piece of iron, and indeed present all the properties of a powerful magnet. These magnetic properties are, however, transient, and are manifested only whilst the electric current is traversing the helix, vanishing altogether on the electricity ceasing to pass through the wire.

As in this experiment the electricity does not *enter* the iron, but merely passes round it in the coil of wire, we learn that an electric current traversing a wire possesses the property of inducing magnetism in iron bars brought within its influence, and placed with their axes at right angles to the direction of the current. If they be not placed in this position, the magnetism induced is proportionably weaker.

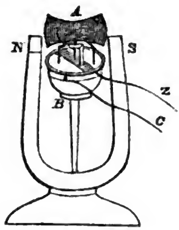
484. If a bar of soft iron be bent in the shape of the letter U, and be covered with several series of folds of copper wire, insulated by being covered with cotton, and a current of electricity be transmitted through the wire, by connecting its two ends to the plates of an electromotor, the intensity of the induced magnetism will become very obvious. On placing a smooth bar of soft iron opposite to the poles of this *electro-magnet*, it will be attracted, and remain firmly adherent; and an immense weight may be suspended to the bar without separating it from the poles of the magnet. In this manner, *electro-magnets*, capable of supporting several hundred-weight, and even tons, have been constructed. It is remarkable, that if the contact with the electromotor be broken, whilst the poles of the electro-magnet are unconnected with each other, the induced magnetism will, if the iron be very soft, nearly entirely vanish. But if the poles be connected by a bar of soft iron, before communication with the source of electricity be interrupted, a considerable magnetic intensity is left in the curved iron bar, and is permanent so long as its poles are connected, disappearing only on the removal of the piece of iron adhering to them.

485. If bars of hard iron, or steel, be substituted for soft iron, litle or no magnetism is developed, so long as the electricity traversing the helix in which they are placed is of low tension. But if a current from a powerful voltaic battery, or the discharge of a Leyden jar, be transmitted through the coil of wire, the included bar, if it be small, as a steel needle, becomes *permanently* magnetic, its polar properties not disappearing, as in the case of soft iron, on

the cessation of the inducing current. In every case, the *direction* of the poles of the induced electro-magnet bears a constant relation to the course taken by the electric current, and is the same as that in the electro-dynamic cylinder (482).

486. The phenomena of the electric induction of magnetism may be beautifully shown by means of a contrivance of the late Dr. Ritchie, consisting of a bar of soft iron, supported by a pivot, and covered with a coil of insulated copper wire, the two extremities of which just touch the surface of the mercury contained in a circular trough, divided into two cells by a transverse slip of wood. In the marginal figure, NS is an upright horse-shoe magnet, having the bar of iron A covered with a coil of insulated copper wire, supported by its pivot over the two-celled vessel of mercury B. On connecting the latter by the wires CZ to the two plates of an electromotor, the bar A becomes a temporary magnet, and, if the connections be properly made, its ends assume the *same* polar state as the poles NS, to which they are opposed; of course, repulsion ensues, and A performs half a revolution: here its wires pass over the wooden partition, and dipping into the opposite cells of mercury, its polarity becomes reversed, and so on: the bar A revolving with immense rapidity, and having its polarity reversed twice during each revolution. During the action of this apparatus, as well as that of the rotating coil of wire (481), a loud humming noise, often amounting to a loud musical sound, is excited by the rapid vibratory motion assumed by the fixed magnet during the rapid revolution of the electro-magnet, or wire coil. This musical sound is remarkably well observed when the magnet is supported by three levelling screws, on a smooth table; and if the apparatus be large, it much resembles the drone of the bagpipes.

Fig. 256.



487. If the electro-magnet (486) be about four or five inches in length, it will rotate by the magnetism of the earth, independent of any steel magnet in its neighborhood. Care must in this case be taken to place the bar in the magnetic meridian, and allow the electric current to traverse the wire coiled round it, in such a direction, that the poles of the temporary magnet may be such as will be repelled by the hemisphere of the globe, to which they are opposite.

488. It has been proved that a conducting wire and a magnet, by their mutual reaction, tend to arrange themselves in a direction at right angles to each other (463), and that if the action of the current, or what comes to the same thing, of the wire conveying it, be limited to one pole only of a magnet at a time, they will tend to rotate round each other in a given and constant direction (473, 474). Wires conveying currents, it has been shown, also possess the properties of mutual attraction, or repulsion, according to the direction of the electric fluid (471), and of being acted upon by the magnetism of the earth, or of a steel permanent magnet, arranging themselves in a constant direction, with regard to the poles of either (478). Ampere has extended these facts still further, by showing that two electric currents properly arranged will even tend to rotate round one another, providing their direction be at right angles to each other. Thus, if a *fixed* current of electricity be supposed to be moving from E to B, as in fig. 1, p. 251, and a movable current be supposed to be placed as in CD, whilst the positive fluid in AB and CD is moving in the direction shown by the arrows, attraction will take place between the current EB and CB, in the angle CEB; for if CD be inclined towards EB, the currents in each will be moving in the same direction. Repulsion

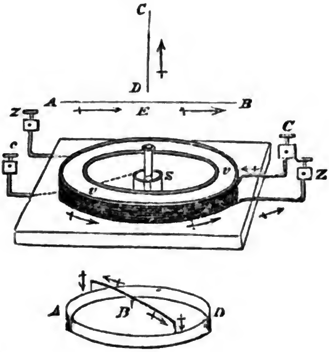
will be exerted in the angl e AEC, between CD and AE; for if CD be supposed to be inclined towards AE, the currents in each will move in opposite directions. If then the current AEB be circular, the movable current CD will tend to revolve round it.

489. This may be proved by surrounding the circular copper trough *vv*, fig. 2, with some thick insulated copper wire, connected with the binding screws ZC. The metallic support S is connected, by a wire, with the screw or cup *c*, and the trough *v* itself with the screw or cup *z*. A light wire frame, ABD,

Fig. 257.

Fig. 1.

Fig. 2.

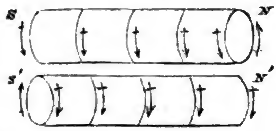


furnished with a hoop or circle of thin copper, is provided with a pivot at B, by which it may rest with as little friction as possible on the support S. Fill *v* with dilute sulphuric acid, place ABD on S, so that its hoop may just dip in the dilute acid in *v*, connect CZ and *cz* to the copper and zinc plates of an electromotor, respectively. Under these circumstances, currents of positive electricity will traverse the wire wound round the trough *v*, and along the frame ABD, in the direction pointed out by the arrows: and the horizontal circular current in the wire acting on the descending vertical currents in ABD, will cause the latter to revolve in a direction varying with the course of the current in the wire surrounding the vessel *v*.

490. From the phenomena detailed in this chapter, a highly ingenious theory of magnetism has been proposed by Ampere, differing altogether from the conventional hypothesis already explained (258), in denying the existence of any magnetic matter as distinct from electricity, and considering that all magnetic phenomena are but the visible effects of invisible electric currents, permeating the iron bars or other substances in which they exist. According to this theory, every molecule of a magnet must be regarded as being surrounded by a current of electricity, constantly and perpetually circulating around it; and that the only difference existing between a magnet and a mere bar of iron, is simply, that in the latter, the electricity present is in a latent and quiescent state; whereas, in the former, it is in a state of rapid rotation around each ultimate atom or particle of iron. All the effects produced by these elementary currents, may be theoretically represented by a set of resultant currents surrounding the mass, as shown in the following figure. The end N of such a bar will be the austral pole and point towards the northern

hemisphere of the globe, because there the currents of positive electricity represented by the arrows, are moving in a direction from left to right, or opposed to those of the hands of a watch (479.) The opposite end will, con-

Fig. 253.



sequently, be the boreal pole: for, on looking at the face s, as shown at s', the currents will *appear* to be moving from left to right; for the same reason that a word is seen backwards, on looking at it through the paper on which it is written, by holding the latter between the eye and the light.

491. The attraction between the magnetic poles of different names, and repulsion between those of the same kind (254), are on this theory explained by supposing that, in the former case, the elementary currents are moving in the same, and, in the latter, in different, directions (471). The rotation of a conducting wire round a magnet (474) becomes also reduced to the simple case of the rotation of a vertical round and horizontal current (489); for all magnets, it must be recollected, are, on this hypothesis, supposed to have myriads of currents traversing them, in a direction at right angles to a line connecting their poles.

On this theory, also, the magnetism of the earth is explained, by supposing the existence of currents of electricity constantly traversing it in a direction, of the positive, from east to west, and of the negative fluid, from west to east. It must be confessed that, opposed as this view is to the generally received theories, it has received much support from the recent discoveries in electro-magnetic induction (493).

CHAPTER XVIII.

ELECTRO-DYNAMIC INDUCTION, OR MAGNETO-ELECTRICITY.

General Statement, 492. *Secondary currents induced, by electricity*, 493—*by magnets*, 494—*by electro-magnets*, 495—*in the same conductor with the primary current*, 496—*Calorific effects of*, 497. *Shock from secondary currents*, 498. *Currents excited by revolving disc*, 499. *Electro-magnetic machines*, 500—*without iron*, 501—*with alternating currents*, 503—*single currents*, 505—*with an electro magnet*, 510. *Magnetic theory of Ampere*, 512.

492. Of all the numerous and successful researches made by Faraday, in the different departments of electrical science, none are of greater importance, or more worthy of deep attention and study, than the discovery of electro-dynamic induction, which was made by that philosopher in 1831. As a brief generalization of this discovery, it may be stated that, whenever an

electric current traverses a wire, it excites a current in an opposite direction in a second wire held parallel to it; and on suddenly stopping the *primary* current, the induced one re-appears, but in an opposite direction to that which it first followed. Whenever, also, a magnet is moved before a conducting wire in any manner, but especially when the long axes of both magnet and wire are at right angles to each other, similar electric currents are excited or induced in the wire. These *induced* or *secondary* currents are but of momentary duration, appearing only at the instant the primary or inducing current either effects its passage, or ceases to pass through the wire; and, when excited by the magnet, existing only during the movement of the latter, ceasing the instant it comes to a state of rest.

493. Coil on a wooden cylinder, about two inches long, and an inch in diameter, about eight or ten feet of insulated copper wire, (*i. e.*, covered with cotton or silk thread,) and let its two ends project; call these A and B; over this, coil forty or fifty feet of copper wire, also insulated, and separated from the first coil by several folds of silk; call the free ends of this second coil, CD. Then connect CD to the screws GG of the multiplier (468), and A to one of the plates of an electromotor (400): suddenly bring B in contact with the other plate, and immediately the needles of the multiplier will move from an induced electric current, traversing the coil CD. This being only of momentary duration, the needles will soon regain their former position: then *rapidly* remove B from the plate of the electromotor with which it was previously in contact, and the needles of the multiplier will again move, but in an opposite direction to that in which they first deviated. In this experiment we see that a current traversing a wire *induces* a secondary one in a wire parallel to it, (considering the curves formed by the wires as being constituted of an infinite series of planes,) both at the instant of making and breaking connection with the source of electricity. These currents are always opposed to each other in direction, as proved by the multiplier, and must be considered as arising from *induction*, because the wire traversed by the *primary* or battery current was insulated completely from that in which the *momentary* current, acting on the multiplier, was developed.

494. Coil on a hollow cylinder of pasteboard, half an inch in diameter and three inches long, about fifteen feet of *insulated* copper wire, and connect its two ends to the screws GG of the multiplier (468); then pass into the hollow axis of this helix a cylindric magnetic bar: the needles of the multiplier will instantly move, showing the existence of a current traversing the coil. Allow the bar to rest in the cylinder, and the needles will return to their primitive position, the induced current disappearing. Suddenly *withdraw* the magnetic bar, and the rapid motion of the needles of the multiplier will indicate the momentary existence of an electric current in a direction the reverse of that, which appeared on *introducing* the bar into the helix. If the opposite pole of the bar be passed into the coil, the induced current will be in opposite directions to that produced by the action of the other pole.

495. Wind round a cylinder of soft iron, or a bundle of iron wire, a few feet of insulated copper wire; let its free ends be called AB. Over this coil, wind about twenty or thirty feet of insulated copper wire, carefully separated from it, and connect its free ends to the multiplier as before. On connecting AB to the plates of an electromotor, an electric current will pass through it, and convert the included iron bar into an electro-magnet (484). The magnetism thus set in motion in the bar will, like the movement of the permanent magnet (494), induce a current of electricity in the outer coil connected with the multiplier, and its needles will be powerfully acted on. Then break connection with the electromotor by removing A or B from the plate with which either was in contact, magnetism will vanish from the iron bar, and an ener

getic current of electricity in an opposite direction will be excited in the inner coil, causing the needles of the multiplier to deviate with velocity from their former position.

496. A second coil of wire is by no means necessary for the development of an electric current: a single length of *insulated* wire, coiled into a tolerably compact helix, having an induced current excited in it in one direction, on *making* connection, and another, in an opposite direction, on *breaking* connection with the battery, or other source of electricity. These induced currents, like those before described, are but of momentary duration, and are always opposed in direction to the primary current; they may be considered as arising from the reaction of the primary current traversing each fold of wire, on the electricity naturally present in the adjoining folds. In this manner is explained the appearance of a vivid flash of light, observed on *breaking* connection with a small electromotor, by means of a wire folded into a compact coil, whilst scarcely the faintest spark is perceived when a short wire, or long *unfolded* one is used. If connections be made and broken by means of a cup of mercury, the vividity of the light is increased by reflection from the brilliant surface of the fluid metal, as well as from the latter undergoing combustion by the force of the discharge. If the wire be folded round a bar of iron, the induced magnetism will increase the intensity of the secondary current, and consequent splendor of the spark, on breaking contact with the source of electricity. In this manner are explained the vivid sparks observed during the rotating of a flat coil (481), and of an electro-magnet (486).

497. If about sixty feet of thick *insulated* copper wire be wound into a short compact coil or helix on a short wooden reel or bobbin, the effects of these secondary currents may be beautifully observed. The battery employed may be an electromotor of a single pair of plates (400); let these plates be called Z and C.

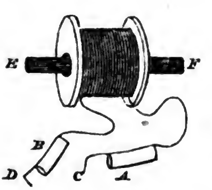
(A.) Connect one end of the helix with Z, and fix on C a cup of *mercury*; introduce the other clean and sharp end of the helix wire into the mercury, and withdraw it with a jerking motion, a vivid flash of light will ensue. The heat evolved is sufficient to inflame ether, or gunpowder, when placed on the surface of the fluid metal.

(B.) Connect one end of the helix, as before, to Z, and fix on C a clean steel file, draw the other end of the wire over the surface of the file, and a succession of brilliant sparks, from the brilliant combustion of the steel, will appear.

(C.) If connection with the electromotor be broken by means of the helix arranged as before (B.), but with one end of the wire furnished with a piece of leaf-gold or silver, combustion of these metals, attended by the evolution of their characteristic light (427), will ensue.

498. Let about 200 or 250 feet of *insulated* copper wire be coiled on a hollow wooden bobbin or reel, about two inches long; and furnish each end of the wire with brass or tinned iron cylinders, A B, terminating in metallic points, C D. Grasping these cylinders with the hands, immerse C in a cup of mercury connected with the plate of the electromotor, and D, in a second, connected with the other plate; suddenly withdraw one of them, as D, and the secondary current thus excited, in completing the circuit from A to B, rushes through the arms of the person grasping them, producing a severe electric shock. If the hands be moistened, to render them better conductors, and connections be made and broken with the electromotor, by connecting C to one plate, and

Fig. 259.



drawing D over the surface of a file connected with the other (497, B), a rapid succession of very painful electric shocks will pass through the arms and chest of the operator. By placing in the hollow axis of the reel a bar of soft iron, or, still better, a bundle of soft iron wire EF, the intensity of the induced current, the vividity of the sparks, and strength of the shocks, will become remarkably increased.

These shocks have been by many persons most erroneously regarded as produced by a single pair of plates, whereas they really arise from a secondary induced current, quite independent of (except that it is excited by it), and far exceeding in intensity, the current originally generated by the electromotor.

499. In all pieces of electro-magnetic apparatus, in which the contact with the battery is suddenly broken, a vivid spark is seen from the induced current excited by the action of the magnet used, on the conducting wire. This may be seen in the vibrating wire (476), where each time the moving wire leaves the mercury, a vivid spark is observed; although the electromotor itself may be incapable of affording one. The existence of these currents may be very satisfactorily proved by means of the revolving disc (477), by replacing the stellated wheel W (see fig.) with a disc of copper, so large, that it may just dip into the mercury in the trough. Allowing the magnet to remain in its place, connect the cups ZC with the screws GG of the multiplier (468), and cause the disc to revolve rapidly, by giving it a slight blow with the finger; the needles of the multiplier will immediately move from the influence of an electric current excited by the inductive action of the magnet on the revolving disc.

500. The currents thus excited (493—499), are available for all the experiments in which ordinary voltaic electricity is applied, and various pieces of apparatus, termed *magneto-electric* and *electro-magnetic* machines, have been contrived for the purpose of exciting them with rapidity. These may be divided into three principal kinds, in two of which an *electric current* is employed as the primary exciting agent; and in the other, a permanent magnet is used.

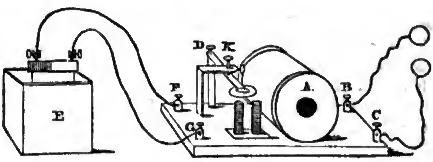
501. The simplest and most convenient form of electro-magnetic machine is founded on an experiment already described (493), and may be constructed by winding on a wooden reel, about three inches in length, with a hollow axis, sixty feet of insulated copper wire of about the sixteenth of an inch in diameter, its terminations being soldered to binding screws: this is termed the *primary coil.* Over this, wind about 1300 or 1400 feet of insulated copper wire, about the sixtieth of an inch, or even less, in diameter, and solder its terminations to binding screws: this constitutes the *secondary coil.* If then, the primary coil be connected with the electromotor, whilst the ends of the external or secondary coil be held in the hands, especially if tin or copper cylinders be used to increase the extent of surface for contact with the hands, on breaking contact with the source of electricity, all the electric fluid present in the exterior coil is set in motion by the inductive influence of the primary current, and passes through the body of the operator, producing a severe shock. If the terminations of the long wire dip in acidulated water, or rest on paper moistened with a salt, as iodide of potassium, electrolytic action results, and the proximate elements become separated.

502. It is obvious that some means of breaking contact with the battery with sufficient rapidity is necessary to ensure a rapid succession of electric currents; and for this purpose various plans have been proposed. Ratchet and cogged wheels have been long employed for this purpose; but as they involve the necessity of being turned by the hand, they are very troublesome. If any apparatus of this kind be employed, instead of a cogged wheel, a cylinder of wood having two bars of metal inlaid, connected with the electromo

tor through the *primary coil*, should be used. A brass spring, connected with the other plate of the battery, presses upon the cylinder, and on causing the latter to revolve by means of a multiplying wheel, the contact with the battery may be rapidly broken. Connecting the *primary* coil to the electromotor through the medium of the vibrating wire (476), stellated wheel apparatus (477), or still better, of the rotating coil (481), or magnet (484), will answer very well, as contact will be effectually broken several times in a second, by their action. I prefer, however, a little apparatus which I have described elsewhere,* consisting of a light iron beam vibrating between two fixed magnets; this enables us to break contact about 400 times in a minute, and consequently affords a rapid succession of currents of induced electricity.

503. The most convenient form of the electro-magnetic machine is, however, the following; it is far superior to that which I contrived, on account of its certainty of action and dispensing with the use of mercury. It consists of a

Fig. 260.



wooden bobbin A, on which the two coils of wire already described are wound (501,) the ends of the long and fine coil being soldered to the binding screws BC. An end of the short and thick (primary) coil is soldered to the beginning of the copper wire surrounding the two little vertical bars of soft iron, its end being connected with the screw G. The other extremity of the short coil is soldered to the base of the brass column D. This column supports a slip of elastic brass, bearing at its end a disc of soft iron, suspended over the vertical iron bars. A slender screw K, furnished with a platinum point, passes through the top of a bent support of brass, and gently presses on a plate of the same metal fixed on the slip of brass below it. The end of this support is connected with the binding screw F. All these connections are made under the base of the instrument.

On connecting a single pair of plates E, with the screws FG, the iron bars become magnetic by induction (484), and attract the disc above them. This being drawn down, breaks the contact between the end of the screw K and the brass spring, and of course the magnetism in the bars vanishes. The elasticity of the spring causes it to touch the end of K; contact is thus made, the bars again become magnetic, and so on. The course of the current from the plates E to the primary coil on A being thus interrupted and renewed many hundreds of times in a minute, a loud musical sound is produced by the vibrations of the brass spring. Of course with each of these renewals and interruptions of the primary current, induced currents traverse the secondary coil, which becomes remarkably increased on placing a bundle of soft iron wire in the hollow axis of the bobbin A. On then grasping a pair of conductors connected with BC in the hand, a rapid succession of severe shocks will be experienced.

504. From what has been already remarked (492,) it is obvious that the induced currents thus excited will be alternately in opposite directions. Those

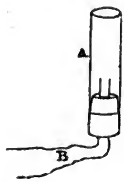
* Phil. Magazine, November, 1837.

excited when contact is broken with the battery being much more energetic than those excited when contact is made. The following experiments will be found instructive.

A. Place on a plate of glass a slip of bibulous paper, a mixed solution of starch, and iodide of potassium; let the points of two platinum wires fixed to the screws B C rest on this paper, the blue iodide of amidine will appear at both wires, a much larger quantity being developed at one than the other.

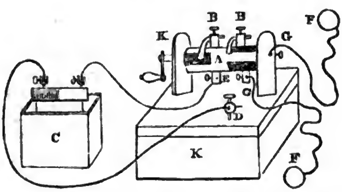
B. Let two platina wires B be thrust through a cork fixed in the end of a glass tube A, filled with dilute sulphuric acid. Connect the wires with the screws B C. A torrent of minute bubbles of mixed oxygen and hydrogen gases will be evolved from both wires. One giving off, however, much more than the other.

Fig. 261.



505. The apparatus just described may be conveniently called the electro-magnetic machine with alternating currents. It is, however, often important to be able to obtain the induced currents separately, hence the contrivance of the electro-magnetic machine with single currents. The following is the most convenient arrangement of this kind, as contact is broken by solid conductors. In this, the double coils with their axis of iron wire, are placed in a box. One end of the primary coil being soldered to the screw D, the other to the brass upright K. A wooden cylinder A, with pieces of brass inlaid at either end, is connected thus with the brass uprights K G. Slips of elastic brass press upon

Fig. 262.



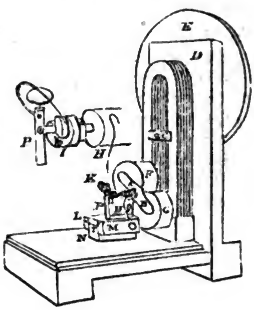
it from B B, supported by the brass columns E G, to which the extremities of the secondary coil are soldered. All these connections are made within the box. On connecting the conductors of a battery of a single pair of plates with E and D, and revolving the cylinder, a glance at the figure will show that from the alternate arrangement of the slips of brass, induced currents can traverse the wires F F; and thus, by properly arranging the connections of the battery, we can make such wires convey positive or negative currents at will.

If the experiments made with the apparatus with a double current (504)

be repeated with this, the iodine and potassium in the one case, and oxygen and hydrogen in the other, will be set free at one wire and not at both.

506. Of the magneto-electric machine, in which a permanent magnet is the exciting cause of the currents, there are many varieties. Of these, Saxton's and Clark's arrangements are superior to those of Pixii and others; that of Mr. Clark being upon the whole more convenient than Saxton's, from its small bulk, its intensity of action, and its dispensing with the use of mercury. This consists of an upright compound horse-shoe magnet, pressed against a board, D, by the cross-piece C. By means of a multiplying wheel, E, the armature ABFG is made to revolve rapidly before the poles of the fixed magnet. This armature consists of two pieces of soft iron, connected at right angles to the piece of iron AB by screws; round the legs or branches of this are wound about 1500 yards of fine, *insulated* copper wire; one end of which is connected to a collar of brass, against which the spring H presses, the other end being soldered to an insulated brass collar, I, part of whose circumference has been removed, as shown on a larger scale in the side figure. A thick copper wire, K, presses against I, and is connected by a brass pillar, P, with a metallic strap, L, fixed on one side of the wooden block N, whilst a similar piece of metal, M, with which it is connected by a bent wire, T, is on the opposite side, and supports the spring H. When FG, and consequently their iron axes,

Fig. 263.



are opposite to the poles of the magnet, the latter, by induction, converts the included iron into a temporary magnet: at the instant this action occurs, the electric equilibrium of the wire wound round it becomes disturbed, and a current of electricity rushes through the coil. If the armature be turned half round, the magnetism of the iron piece becomes reversed, and a second current in an *opposite* direction is excited; and as at the moment this takes place, the wire K comes in contact with the interrupted portion of the collar I, a bright spark passes between them. On revolving the armature with rapidity, a succession of vivid sparks ensue; and if wires fixed to the brass pieces LM be immersed in acidulated water, decomposition of that fluid will occur, the oxygen and hydrogen gases being evolved alternately from each wire—as of every two induced currents, one is always in opposite direction to the other, the alternate ones only moving in the same direction.

507. If a copper cylinder be grasped in each hand, whilst wires connected with them communicate, one with the strap L, and the other with a cavity

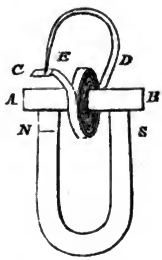
excavated in the end of the revolving armature; on turning the wheel E, a rapid succession of currents is sent through the body of the person grasping the cylinders, producing a series of severe and almost intolerable shocks, the muscles becoming so firmly contracted that he is generally unable to drop the conductors.

If the wires, instead of terminating in copper cylinders, be furnished with platina points, electrolytic decomposition of any conducting fluid they are immersed in will ensue, as in the case of the induced current of the previously described apparatus.

508. If an armature, having a *short* helix of thick insulated copper wire, be substituted for the armature AB, in the machine just described, the intensity of the evolved electric currents will be diminished, and no shock or chemical action will result from them. The vividity of the spark at I will be, however, increased, and pieces of platina wire readily ignited by allowing the electricity to pass through them. The ordinary phenomena of electro-magnetic rotation may be produced by passing these currents from the short helix through the appropriate pieces of the apparatus (477).

509. A very simple and ready mode of exhibiting the electro-magnetic spark as it is termed, by the induction of a permanent magnet, is to wind round a piece of soft iron AB, about ten yards of thick insulated copper wire or ribbon. Let one end of this coil be soldered to a plate of amalgamated copper C, upon which the other end, sharply pointed, is made to press with elasticity; to effect which, it is bent into an elliptical form DE. On placing this armature on the poles of a strong magnet, NS, the bar AB becomes magnetic by induction; and on suddenly *jerking off* one end, as B, from the pole S, the bar nearly loses all its polarity, and the electric current developed is shown by a vivid spark occurring at the point where E presses on C, as it becomes slightly raised from the plate by the sudden motion communicated to AB.

Fig. 264.

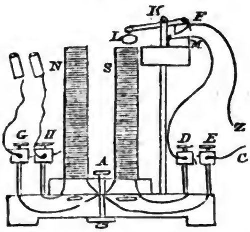


510. As in these cases the electricity evolved bears a ratio to the magnetism induced in the iron nucleus of the armatures, it follows, that by increasing the intensity of this magnetism, the electric current becomes proportionably increased in tension and quantity; as by means of a current of electricity of low tension we can excite powerful magnetism in an iron bar, the application of this as the inducing agent, has been used in the construction of these machines: indeed, it was by a contrivance of this kind, that Faraday first discovered the existence of these currents. The most powerful electro-magnetic machines I am acquainted with are constructed on this principle; the following is a description of one of them. Two bars of very soft iron NS, about fourteen inches long, and an inch in diameter, are connected by a cross piece of iron, A, firmly screwed to them. These bars are covered with a coil of insulated thick copper wire, about 300 feet in length, the ends of which are connected to the screws DE. Over this are wound about 1600 feet of very thin *insulated* and *varnished* copper wire, its ends being connected to the screws GH.

On connecting DE with the battery of about ten pairs of plates, the iron bars become sufficiently magnetic to lift about sixty pounds weight; and if the copper cylinders, connected to GH, be grasped with the moistened hands, an almost insupportable shock will ensue, on breaking connection with the battery. To effect this rupture of contact with facility, a contrivance similar to that used

by Mr. M'Gauley* will be found very useful: this consists of a beam of brass supported by a horizontal axis at K, having at one end a ball of soft iron, L,

Fig. 265.



suspended, and at the other a fork of thick copper wire, so arranged that by its own weight it will fall into two cups of mercury fixed at M, and thus connect them with each other. One of these cups is connected by a wire with a screw D, whilst the other is, by a wire Z, connected with one end of the battery, the screw E being in communication with the other. As soon as these connections are completed, the bar S, becoming magnetic, attracts the ball L, which, falling, raises the fork M from the cups; thus breaking contact with the battery, and producing a vivid spark attended with a loud snap, and combustion of the mercury. The bars losing their magnetism, the fork F falls by its own weight, and re-establishes connection with the battery; L is again attracted, and so on, the beam rapidly vibrating amid a complete shower of sparks from the mercury, producing a most brilliant spectacle in a dark room.

511. As a rapid succession of powerful alternating currents circulate at each rupture of contact through the long coil, the shock felt at the screws GH, or at the cylinders connected with them, becomes intensely painful, completely paralyzing the arms of the persons grasping the conductors. With these currents evolved at GH, the chemical decompositions already described (434) may be performed and other effects produced, as with a voltaic battery. If a piece of charcoal be placed on G, and a platina wire connected with H be drawn lightly over it, whilst the machine is in action, a series of minute sparks from the induced currents will be observed.

512. As electric currents are induced by other currents passing *near* the conductors, in which they are excited, the theory of Ampere (490) receives considerable support from the facts enumerated in this chapter. Granting with him that a magnet is full of perpetually moving currents of electricity, it induces magnetism in a bar of iron, by exciting similar currents, as in the case already mentioned (490), and then the remarkable fact of magnets exciting electric currents in wires moved near them, will be resolved into the same case of currents exciting currents. In fact, it permits us to generalize the phenomena of magnetism and electro-dynamics, in a very important and satisfactory manner. The apparently mysterious phenomena produced by revolving plates of different metals under magnetic needles, in causing them to move, may be referred to a similar explanation; the currents in the needles exciting similar currents in the revolving plate, which by their reaction on the needles cause them to oscillate and revolve.

* Rep. British Association, vol. vi. p. 24.

CHAPTER XIX.

THERMO-ELECTRICITY.

Excitation of thermo-electric currents by two metals, 513—*by one metal unequally heated*, 515—*unequal distribution of heat necessary*, 516—*rotations produced by*, 517—*thermo-electric piles*, 519—*chemical decompositions? and sparks from currents induced by*, 520. *Currents evolved by metals plunged into fused salts*, 521.

513. When two different metals, as copper and bismuth, are soldered together and connected by wires to a multiplier (468), an electric current becomes developed on heating the point of juncture of the two metals with a spirit lamp. If the multiplier be sufficiently delicate, the deviation of the needles will occur when the point of connection of both metals is grasped in the hand; a very slight elevation of temperature being sufficient to produce this effect. In general, the most powerful currents are evolved by heating the more crystaline metals, as bismuth and antimony; and they increase within certain limits with the increase of temperature. The following list contains the names of several metals, any two of which being employed as a source of electricity, by heating them at their point of junction, currents are developed in such a manner that each metal becomes positive to all below, and negative to all above it, in the list:

+Bismuth
Platina
Mercury
Lead
Tin
Gold
Silver
Copper
Zinc
Iron
—Antimony.

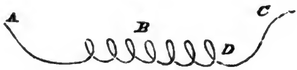
514. This mode of developing electricity was discovered in 1821, by Prof. Seebeck, of Berlin, and has been studied with success by Prof. Cumming of Cambridge, Mr. Sturgeon, and many other philosophers. In examining these currents, as they are of too low intensity to force their way through very long conducting wires, the multiplier should be constructed in the manner already exlpained (468,) but the coil should be short, and composed of thick and soft copper wire, so as to offer as little opposition as possible to the passage of the electricity.

515. It is by no means necessary to employ two metals in these experiments, for if two pieces of copper wire be twisted together, and connected with the multiplier, a current of electricity takes place on holding a spirit-lamp on one side of the juncture. Even platina wires will evolve these currents; so that they are to be regarded as arising from a series of decompositions and recombinations of electricity produced by the action of heat, and not resulting, at least necessarily, from oxidation or other chemical action. When a uniform bar of metal is heated at one end, the cold portions assume negative and hot ones positive electricity.

516. For the development of thermo-electric currents it is necessary that the

heat applied should not be equally propagated through the metal. Thus, if the two ends of the wire of the multiplier be connected by means of a loop of platina wire, and a spirit-lamp be held near any part of the latter, no sensible current will be evolved. But if some obstruction be made to the equal propagation of the heat, or by rolling part of the wire into a spiral, and heat be applied to one side of this, an electric current is excited. Thus, let ABC be

Fig. 266.

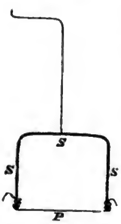


a platina wire connected with the multiplier and rolled into a spiral at B. On heating the part D with a spirit-lamp a positive current passes from D to A, and causes the galvanometer needles to deviate from their position.

517. The phenomena of electro-magnetic rotation may be readily produced by means of thermo-electric currents; for this purpose twist round each end of a bar of bismuth an inch in length, a thick copper wire, and having amalgamated the other ends, immerse them in the circular troughs AB of the apparatus for the rotation of a conducting wire round the pole of a magnet (474). Apply a spirit-lamp to one end of the bar of bismuth, and as soon as the latter becomes warm, a current of electricity will pass through the apparatus from the copper to the bismuth, and the conducting wires suspended on the poles, will begin to revolve with rapidity.

518. A very ready mode of demonstrating the excitation of electric currents by heat, by means of their electro-dynamic effects, is met with in the little apparatus contrived by Professor Cumming. A piece of thin silver wire is bent into the figure SSS, and suspended by a filament of silk from any support, the lower arm of the rectangle being composed of platina, P. If the flame of a spirit-lamp be applied to one of the junctures of these wires, and a horse-shoe magnet be held near one of the vertical arms, attraction or repulsion will ensue, according to the direction of the current and the position of the poles of the magnet (478).

Fig. 267.



519. The intensity of these currents is increased by combining a series of alternations of two metals, as copper and platina, or bismuth and antimony, as in the ordinary electric pile. By using very short and slender bars of bismuth and antimony, having their alternate ends soldered together, and packing a series of 36 into a cylindrical bundle, we acquire an arrangement in which the electric equilibrium is disturbed by the slightest alteration of temperature of either end of the bundle (845). If one of the faces of the bundle be blackened, the mere approach of the hand is sufficient to excite a very perceptible electric current; to detect which a multiplier with a thick, well-annealed copper wire should be employed. This instrument then becomes a most sensible thermoscope, infinitely exceeding all forms of thermometer in indicating alterations of temperature, and in the hands of Forbes and Melloni, has led to the beautiful discovery of polarization of heat (853).

520. Thermo-electric currents are of too weak tension to produce satisfactory evidence of effecting chemical decomposition. It has been, however, stated that by the current excited by a large number of alternations of platina and iron, M. Botto, of Turin, succeeded in decomposing water and various saline

solutions. In 1836, Chev. Antinori of Florence, by connecting a thermo-electric battery with a helix of insulated copper wire, about 500 feet in length, obtained on breaking contact a vivid spark from the induced or secondary current produced by the passage of the primary thermo-electric current (497). Shortly afterwards, Prof. Wheatstone* repeated this experiment with success, using a battery of thirty-three pairs of bismuth and antimony, forming a cylindrical bundle, 1·2 inch long, and 0·75 inch in diameter, with a coil of *insulated* copper ribbon 50 feet long, and 1·5 inch broad. Mr. Watkins† has since obtained the same results, by using a single pair of plates of bismuth and antimony, each being 0·5 inch long, 0·12 inch thick, and weighing but five grains. The same gentleman, by using a thermo-electric battery of thirty pairs, each plate being 1·5 inch square, and 0·33 inch thick, and heating one end of the arrangement with a hot iron, whilst the other was kept cool with ice, succeeded in exciting an electro-magnet to such an extent as to support a weight of ninety-eight pounds.

521. Dr. Andrews, of Belfast,‡ has discovered that platina wires connected with a multiplier, and plunged into fused salts, are traversed by an electric current. This may be shown by connecting a piece or platina wire with one screw of the multiplier, and bending its free end into a loop. On fusing a little borax in the loop, by means of the blow-pipe, and quickly inserting the previously *heated* end of a second platina wire also connected with the multiplier, into the fused bead, the needles flew to the extreme of the scale, from the development of a powerful current. The direction of the positive current appears to be from the hot platina wire, through the fused salt, to the cold wire. By means of these curious thermo-electric currents, Dr. Andrews succeeded in obtaining distinct evidence of chemical decomposition. The same results were obtained when other fused salts, as carbonate of potass, chlorides of potassium and strontium, iodide of potassium, sulphate of soda, and even boracic acid, were used.

CHAPTER XX.

PHYSIOLOGIC ELECTRICITY, OR GALVANISM.

Electric fishes, 522. *Torpedo*, 523. *Gymnotus*, 524. *Silurus*, 527. *Electric insects*, 528. *Galvani's discoveries*, 529. *Animal electricity*, 530—533. *Matteucci's researches*, 534—537. *Electricity of frogs*, 538—*of man*, 539. *Origin of animal electricity*, 540—543. *Uses of*, 545—548. *Vegetable electricity*, 549.

522. Certain fishes have, from remote antiquity,§ been well known to possess the property of communicating a benumbing sensation to persons who have incautiously grasped them. This remarkable effect, whose intensity is sometimes so great as to amount to a severe shock, has been most satisfactorily traced to electricity; and no real difference exists between the electric fluid thus *secreted*, or *excited* by these animals, and any of the other modifications of that curious form of imponderable matter already described. The fishes hitherto met with, which possess this extraordinary faculty, are but few:

* Phil. Mag., x. p. 414. † Ibid., vol. ix. pp. 304, 399. ‡ Ibid., vol. x. p. 433.
§ Aristotle, Hist Anim., lib. ii.. cap. 13, and ix., cap. 37. Pliny, Hist. Nat., lib. xxxii. c. 1. Ælien, de animal. natura., lib. i., cap. 36, &c.

of these the torpedo occelata, and marmorata are alone met with in Europe. The others, including the gymnotus, tetraodon, silurus, rhinobatus, and trichiurus electricus, are confined to the tropics. The torpedo, gymnotus, and silurus have been submitted to very careful investigation: the first, chiefly by Hunter,* Dr. John Davy,† Gay-Lussac,‡ Colladon,§ and Matteucci;‖ the second by Rudolphi,¶ Walsh,** Ingenhouss,†† Humboldt, Bonpland, and Faraday,‡‡ and the last by Rudolphi,§§ and Müller.‖‖

523. The electric organs of the torpedo lie on each side of the head and branchiæ; being made up of numerous five or six sided prisms, placed in such a manner as to present their bases to one surface of the fish, and their apices to the other. Hunter counted 1182 of them in a single organ. They are divided horizontally, by numerous septa, the interspaces being filled up with a gelatinous fluid. These organs are copiously supplied with nerves, which are chiefly branches of the par vagum, or pneumo-gastric nerves. The power of communicating the shock depends upon the integrity of the nerves, for the heart may be cut out, and the animal flayed, without its losing this faculty; but as soon as the nerves are divided, it vanishes entirely. The intensity of the shocks is increased by irritating the origin of the electric nerves with the point of a knife. The electric discharge is directed from one surface of the fish to the other, the electricity of the dorsal surface being positive, and that of the ventral negative; and no shock is experienced unless direct or indirect communication is made between the belly and back of the animal. A complete separation of the two electricities on the two surfaces does not occur, as that portion of the animal nearest the electric organs is positive, or negative, according to the particular surface, with respect to those parts nearer the tail. Dr. Davy succeeded in decomposing acidulated water, and iodide of potassium, as well as of heating but not igniting platina wire, and of magnetizing needles placed in a spiral coil of wire, by means of currents from the torpedo.

524. In the gymnotus, the electric organs are on each side double, and extend from the head to the tail. They are each formed of long horizontal membranous structures, placed at a short distance from each other, provided with numerous transverse septa, and filled, as in the torpedo, with a gelatinous fluid. These organs are supplied by spinal nerves, in which respect it differs from the last described fish; these consist of 224 pairs of intercostal nerves.

The gymnotus resembles an eel in appearance, and is often four or five feet in length; its shock is extremely strong and capable of paralyzing horses and mules. Walsh and Ingenhouss, in 1776, observed a spark to pass between two pieces of tinfoil through which the discharge of this fish was transmitted. This was doubted until, in 1836, the power possessed by electric fishes of yielding a spark was again asserted by Linari; and in 1839 this statement has been placed beyond a doubt by the researches of Faraday, who, availing himself of the electric eel publicly exhibited at the Adelaide Gallery, succeeded in obtaining a current of sparks, by the aid or an inductive coil (423), and

* Phil. Transactions, 1773. † Ib., 1832 and 1834.
‡ Ann. de Chim., lxv., p. 15, joint paper with Humboldt.
§ Séances de l'Acad. de Sciences, Octob. 1836. ‖ Ibid.
¶ Abhand. der Acad. v. Berlin, 1820, 1821.
** Phil. Transactions, 1774.
†† Vermischte Schriften, p. 272. Vienna, 1782.
‡‡ Phil. Trans., 1839.
§§ Abhand. Acad., Berlin, 1824.
‖‖ Handbuch der Physiologie des Menschens, i., p. 66, Coblenz, 1837; or Bailey's translation, London, 1837.

The Tetraodon is described by Paterson in Phil. Trans., 1786, p. 382. The Trichiurus is figured by Willoughby, in his Ichthyology; Appendix, t. 3, fig. 3; and described by Nieuhof in "Zee on Lant Reise door West en Ost-Indien," p. 270, Amsterdam, 1682.

once even by the direct current between the surfaces of two pieces of leaf-gold.

525. Dr. Faraday obtained the electricity from the gymnotus whilst immersed in water, by means of collectors formed of sheet copper bent into a saddle shape, so as to grasp gently the sides of the animal. The back of these collectors were covered with sheet caoutchouc, so as to insulate them from the water. Conducting wires, also insulated by being covered with caoutchouc, were soldered to each conductor. The shock was best obtained by placing one of the hands near the head and the other near the tail of the fish; it was conveyed with facility to the moistened hands by the conductors. When the conducting wires were connected with a multiplier, deflection of the needles to 30° or 40° took place, and was in such a direction as indicated a positive current from the anterior to the posterior extremities of the fish. When the current was allowed to traverse a short helix, a steel needle placed within it became magnetic. In like manner, when the conductors were furnished with platina terminations, and allowed to repose on paper moistened with a solution of iodide of potassium, polar decomposition ensued, iodine being evolved at the end of the wire connected with the anterior part of the fish.

526. On whatever part of the animal the collectors were placed, the current of positive electricity was always found to pass from that nearest the head to that nearest the tail. So that if three collectors were placed on the animal, one near the head, the other on the middle, and the third near the tail, the first was found to be positive with regard to the second, which, although negative with regard to the first, was positive in relation to the third. It appears that the moment the gymnotus wills the shock, the lines of force dart off, diverging from him in the water, and whatever is in their course receives the shock. Hence, if a person immerses one hand only in the water near the fish, when it wills a shock, he receives the blow, although not so powerfully as when in contact with the animal.

527. The silurus is still less known than the gymnotus; its electric organs are double. and are separated by a tough aponeurotic membrane: the most external of these organs lies immediately under the skin, the deeper one being imbedded in the muscles. They are both divided into cells; their nerves are, it is remarkable, the same as both the torpedo and gymnotus, one of the organs being supplied by the pneumo-gastric, the other by the intercostal nerves.

528. Among invertebrate animals, a few have been stated to have claims to be considered as electrical, but this is extremely doubtful. Molina* relates that a certain Chilian spider possesses the property of benumbing the hand of the person who touches it. Kirby and Spence† mention a species of cimex, the *reduvius serratus*, as having the power of communicating what have been regarded as electric shocks. An account is on record, also, of one of the great marine annelidæ, *leonice gigantea*,‡ giving a powerful shock to the person who touched it.

529. Prof. Galvani, of Bologna, in 1791, published a commentary "de Viribus Electricitatis in Motu Musculari," and announced those facts which laid the foundation of that science which bears his name. He then stated that a particular form of electricity, denominated by him *animal electricity*, existed in all animals; and he believed he merely excited and rendered sensible this electricity by coating a nerve and muscle with metals, but did not regard the latter as the real source of the electricity.

This celebrated experiment, although well known, is one of really so marvelous and remarkable a character that, repeat it as often as we may, it can

* Naturgeschichte von Chili, p. 175.
† Introduction to Entomology, i. p. 110.
‡ Silliman's Journal, xv. 357.

never be looked at without a feeling of wonder and delight. Prepare the legs of a frog by denuding them of their skin, and attached by the lumbar nerves to a portion of the spine. Allowing them to rest on a glass plate, z, place a piece of zinc in contact with the nerves, and allow the feet to rest

Fig. 268.

on a thin slip of silver, s. They will of conrse be at rest, and appear, as they indeed are, dead and powerless. . But there exists a power which can be called into action, capable of endowing these dead limbs with an apparent life. The only spell required to evoke this power is a piece of wire, w, one end of which must touch the zinc, and the other the silver plate. Instantly the legs violently contract, and kick away the silver plate.

It has been lately stated by Prof. Matteucci, that this curious observation was not original with Galvani, but was made some time before by the celebrated Swammerdam; and the experiment was exhibited by him in the presence of the Grand Duke of Tuscany.

Shortly after the announcement of this discovery, Prof. Volta, of Pavia, in repeating this and other analogous experiments, arrived at a different conclusion; and he showed that the electricity was really excited by the metals, and the contraction of the muscles of the frog was only an index of its existence. He, however, supposed that the electricity was excited by the mere contact of the metals (395), as the necessary agency of chemical action was not then recognized (398). It is now nearly universally admitted that in this experiment the zinc is acted upon by the chloride of sodium or other salts existing in the fluids with which the tissues of the frog are moistened. Although these and other discoveries of that great man obscured for a time the views and researches of the illustrious Galvani, attention was again drawn to them by the experiments of his talented nephew, Prof. Aldini, of Bologna. He was inspired with so much zeal in defence of his uncle's theory, that he traveled through France and England for the purpose ot demonstrating the truth of his views; and, in the presence of the medical officers and pupils of Guy's Hospital, he in the year 1803, supported and defended a series of propositions so satisfactorily and conclusive, that he was presented by his auditors with a gold medal commemorative of his labors.

530. Prof. Aldini's propositions and conclusions are so important and of such high interest, that I shall now briefly refer to some of them, as they appear to demonstrate, in a most satisfactory manner, the existence of free electricity in animals, and, as will appear to all conversant with this branch of physiology, most remarkably anticipate the late researches of his countryman, Prof. Matteucci.

Prop. 1.—"Muscular contractions are excited by the development of a fluid in the animal machine, which is conducted from the nerves to the muscles without the concurrence or action of metals."*

Exp. (A.)—In proof of this statement, Aldini procured the head of a recently-killed ox. With the one hand he held the denuded legs of a frog, so that the portion of the spine still connected with its lumbar nerves touched the tip of the tongue, which had been previously drawn out of the mouth of

* Aldini. An account of the late improvements in Galvanism. 4to. London: 1803.

Fig. 269.

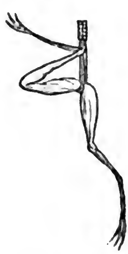
the ox. The circuit was completed by grasping with the other hand, well moistened with salt and water, one of the ears. The frog's legs instantly contracted; the contractions ceasing the instant the circuit was broken by removing the hand from the ear.

The intensity of these contractions was much increased by combining two or three heads so as to form a sort of battery, just as Matteucci forty years after found to be the case with his pigeon and rabbit battery.

Exp. (B.)—Aldini, having soaked one of his hands in salt and water, held a frog's leg by its toe, and, allowing the ischiatic nerves to be pendulous, he brought them in contact with the tip of his tongue. Contractions instantly ensued from a current of electricity traversing the frog's leg in its route from the external or cutaneous to the internal or mucous covering of the body. By this very interesting experiment Aldini demonstrated the existence of the musculo-cutaneous current, and completely anticipated its re-discovery by Donné some five-and-thirty years after.

Exp. (C.)—The proper electricity of the frog was found by Aldini to be competent to the production of contractions. For this purpose he prepared the lower extremities of a vigorous frog, and, by bending up the leg, brought

Fig. 270.



the muscles of the thigh in contact with the lumber nerves: contractions immediately ensued. This experiment is now a familiar one, and has been repeated and modified lately by Müller and others.

Exp. (D.)—A ligature was loosely placed round the middle of the crural nerves, and one of the nerves applied to a corresponding muscle; contractions ensued; but, on tightening the ligature, convulsions ceased.

531. This last statement is very important, as upon its accuracy or error depends what has been regarded as one of the tests of the identity or diversity of the electric and nervous agencies. It was repeated soon after Aldini's announcement of the fact by an Italian physician of celebrity, Signor Valli, who commenced his researches indeed in 1792,* only a year after the publication of Galvani's discovery, and he found if the ligature were applied *near the muscle it did not allow the contraction to occur, but if nearer the spine it did not prevent it.* This was afterwards corroborated by Humboldt. I may here remark that it has been since found by Professor Matteucci, that if care be taken to insulate the nerve, a ligature does arrest the contraction, as well as the passage of a very weak artificial electric current.

532. We must not in this place pass over in silence the neuro-electric theory of Galvani. He assumed that all animals are endowed with an inherent electricity appropriate to their economy, which electricity secreted by the brain, resides especially in the nerves, by which it is communicated to every part of the body. The principal reservoirs of this electricity he considered to be the fibres of muscles, each of which he regarded to have two sides in opposite electric conditions. He believed that when a limb was willed to move, the nerves, aided by the brain, drew from the interior of the muscles some electricity; discharging it upon their surface, they thus contracted and produced the required change of position. This theory was adopted and defended by Professor Aldini.

Valli, to whose experiments I have before referred, believed the neuro-electric fluid to be secreted by the capillary arteries supplying the nerves, by which it became conveyed to the muscles, which he believed to be always in an electric condition, the interior being negative, the exterior positive. He also noticed the curious fact, that in experiments on frogs, the nerves lose their irritability to the stimulus of electricity at their origin first, retaining it longest at their extremities; and on this hazarded an opinion that probably the distal extremities are really the origin of these structures. Both these statements are of deep interest; the former from its bearing on the late researches of Professor Matteucci, the latter from its curious connection with some views of Dr. M. Hall, regarding the peripheral origin of incident nerves.

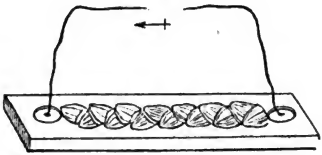
533. It may now be asked, what proof do we possess that the action on muscular fibre to which I have alluded, where no metals are employed, is really produced by electric currents? One great evidence in favor of this opinion is at once found in the fact, that contractions produced in frogs can only be excited when connection is made between a nerve and muscle by a conductor of electricity, all other bodies interfering with the production of this phenomenon. The only thing amounting to positive proof before the researches of Matteucci is an experiment of Valli, in which he formed a sort of battery of fourteen prepared frogs, and by the electricity thus accumulated succeeded in producing the phenomena of divergence in a delicate electrometer. It is to be regretted that no accurate account of this experiment has been left on record; for if true, it must be regarded as most satisfactory in proving the identity of the electricity of the frog with that obtained from other sources.

534. The recent researches of Professor Matteucci,† of Pisa, have, however, completely set this matter at rest. He has incontestably proved that currents

* Wilkinson's Galvanism, 8vo. London, 1804. Page 49, vol. i.
† Philosophical Transactions, 1845, page 283.

of electricity are always circulating in the animal frame, and not limited merely to cold-blooded reptiles, but are common to fishes, birds and mammalia. From the researches of this philosopher it appears that a current of

Fig. 271.



positive electricity is always circulating from the interior to the exterior of a muscle; and that although the quantity developed is exceedingly small, yet that by arranging a series of muscles having their exterior and interior surfaces alternately connected, he developed sufficient electricity to produce energetic effects. By thus arranging a series of half thighs of frogs, he succeeded in decomposing iodide of potassium, in directing the needles of a galvanometer to 90°, and by aid of a condenser caused the gold leaves of an electrometer to diverge. When more delicate tests of the electric current were made use of, their existence was demonstrated in the muscles of all animals, and even of man himself. Dr. Wilkinson* calculated that the irritable muscles of a frog's legs were no less than 56,000 times more delicate as a test of electricity than that of the most sensitive condensing electrometer. Dr. Wilkinson found that two pieces of zinc and silver, each presenting a superficial surface of $\frac{1}{10}$ inch produced violent contractions in the leg of a prepared frog; whilst two large circular plates of zinc and copper required to be brought twenty times in contact with the condenser, before any sensible divergence of the gold leaves of an electrometer was produced. By comparing the area of these plates, multiplied by the number of contacts, with the superficial surface of the minute pieces of zinc and silver employed to affect the frog's leg, he arrived at the conclusion I have just related.

535. Prof. Matteucci availed himself of this circumstance in his contrivance of the frog galvanoscope. This is made by skinning the hind leg of a frog, and separating it from the trunk, taking care to leave as long a piece of sciatic nerve projecting as possible. The leg is then placed in a glass-tube, the nerve hanging over. In using this contrivance all that is necessary is to let the piece of nerve touch simultaneously in two places, the part where electric condition is to be examined. If a current exists, the muscles of the leg will become convulsed at the moment of contact.

Fig. 272.

In this way the Professor detected a current in man, by making a clean incision into the muscles of a recently amputated limb, and bringing the nerve of a frog galvanoscope in contact at once with the two lips of the wound, contraction instantly occurred.

536. In pigeons and fowls, as well as in eels and frogs, currents were readily demonstrable; indeed, by alternating a series of the former by approximating their sides, the raw surface of the muscles of which had been exposed by a quickly made cut, Matteucci formed

* Elements of Galvanism. 1815. 8vo. Vol. ii. p. 316.

a sort of battery resembling that made of the thighs of frogs. The result of this experiment thus proved that energetic currents existed in hot as well as cold-blooded animals. Indeed, more intensely, but very soon disappearing on the death of the animal.

537. By means of the frog galvanoscope (535), not only the existence but the direction of a current can be discovered; for if the leg be kept for a short time before using it, so as to a little diminish its sensibility, the muscles will contract on *making* contact with the body under examination, if the electricity passes from the nerve to the leg, whilst it will contract on *breaking* contact if the electricity is moving in the opposite direction. Using this delicate test for an electric current, Matteucci discovered that the intensity of such currents rises in proportion to the rank occupied by the animal in the scale of being, their duration after death being in the inverse ratio. The Professor discovered that when a mass of muscle belonging to a living animal, or one recently dead, was placed in contact with a piece of wire so that one end of it touched the tendon, and the other the body of the muscle, a current could always be detected circulating in the mass in the direction from the tendon to the external surface of the structure. He further demonstrated the very important fact, that everything which decreases the *vis vitæ* of the animal diminishes the evidence of electricity immediately after death. Thus, when frogs were killed by asphyxia, either by immersion in sulphuretted hydrogen, or water freed from air, the electricity detected in their femoral muscles sunk to a minimum; whilst the thighs of frogs whose hearts had been previously removed gave less evidence of the existence of this important agent than those which had not been thus injured.

538. We have seen that certain fishes (522) possess a peculiar apparatus by which they are enabled to accumulate the electricity developed by the vital processes going on in their structures, and thus produce the ordinarily recognized effects of tension, as shown in the benumbing shock felt on grasping a torpedo or silurus. This endowment is, however, peculiar to very few creatures, and all the electricity developed in the frames of other organisms is only to be detected by comparatively delicate tests. It is, however, very remarkable that in the batrachians generally, especially the frog, an electric current, denominated by Matteucci the *proper current*, possessing some approach to tension, and capable of deviating the needle of a galvanometer to 5°, can readily be detected; its direction is always definite from the feet towards the head. This curious and remarkable fact was, I believe, first pointed out by Nobili, but accurately studied by the Pisan philosopher to whose researches I have so often referred.

539. The different structures of the human body in common with every form of matter, contain a large quantity of electricity in a state of equilibrium. Its existence can be easily demonstrated by merely disturbing this condition. The readiest mode of doing this is by drawing a comb through the hair of a person insulated from the earth by a glass stool (302), and in communication with a condensing electrometer (375). At each stroke of the comb the condensor will become powerfully charged, and on removing its uninsulated plate the gold leaves will diverge most actively. In frosty weather the electric equilibrium is so easily disturbed in this manner that if a person comb his hair before a looking-glass in a dark room, a torrent of sparks will be visible with every movement of the comb through the hair.

540. But there is, however, another state in which electricity exists in animal structures—a dynamic condition, electricity in a free state or in the state of current. This evidently is not anything superadded to the body, but is merely the electricity normally existing in a state of rest and neutral condition, decomposed by some cause or series of causes, by which its positive and

negative elements are separated, their attempt at reunion to reconstitute the neutral electricity giving rise to the phenomena we have been investigating.

It is now an incontrovertible fact that no chemical change can possibly occur without a disturbance of electric equilibrium (395); and many processes of this character are going on in the body. The first in point of importance is the union of carbon with oxygen to form carbonic acid. In the respiratory process, this acid, in the form of gas, is, with aqueous vapor, evolved from the lungs, in addition to a considerable quantity which exhales with the perspired vapors from the surface of the skin. It is nearly impossible to determine the quantity of carbon thus evolved in combination with oxygen with any great accuracy; but it seems pretty certain that about thirteen or fourteen ounces are thus got rid of in 24 hours. During this period the greatest proportion is taken in with the ingesta as mere carbon, and undergoes oxidation in some part of the animal frame. By this union with oxygen, carbonic acid is formed and evolved. Now we have already seen (375) that, if we allow a piece of charcoal to undergo combustion in connection with the condensing plate of a gold-leaf electrometer, the gold leaves will soon diverge with free negative electricity, whilst the stream of carbonic acid escaping from the burning charcoal carries off with it free positive electricity. It is true that the carbon does not, during its union with oxygen in the animal frame, become red-hot and burn with a visible flame; but this does not constitute a serious objection to our regarding the generation of carbonic acid as one source at least of the excitation of free electricity, for the disturbance of electric equilibrium does not depend upon the light and heat evolved, but from the act of union of the carbon with the oxygen.

541. I have here only alluded to the oxidation of carbon; but we must recollect that hydrogen, phosphorus, and sulphur—elements constituting important and essential ingredients of our food—are also thus burnt off and oxidated in the body. These must, like the carbon, become by this very act sources of free electricity. But a more important influence disturbing electric equilibrium is found in the series of decompositions which, in the physiological condition of the body, are always in action. It is impossible that any two elements can be rent asunder without setting free a current of electricity, which, insignificant as it might theoretically appear, is nevertheless competent to the production of many important phenomena. As one among many examples, I would cite the case of common salt, which plays so important a part as an article of food, and for which perhaps alone, of all condiments, a universal appetite exists. In addition to the proportion of this substance which enters the blood unchanged, and becomes an element of all the secretions, a part is decomposed, and one element in union with hydrogen appears as hydrochloric acid in the stomach; another, in union with oxygen, constitutes, as soda, an important constituent of the bile. What, it may be inquired, can be the influence of these apparently infinitesimal evolutions of electric matter, evolved thus from the resolution of a few grains of salt and water into its elements? But it is easy to produce a mass of evidence to show that these small quantities of electricity are more so in appearance than reality. A reference to the powerful electrolytic influence of weak currents will prove this (406, 445).

542. It is a remarkable fact, that when an acid and alkaline solution be so placed that their union be effected through the parietes of an animal membrane, or indeed any other porous diaphragm, a current of electricity is evolved, the causes of which disturbance of electric equilibrium has already engaged our attention (456).

Now, with the exception of the stomach and cœcum, the whole extent of the mucous membrane is in the human subject bathed with an alkaline mu-

cous fluid, and the external covering of the body, the skin, is as constantly exhaling an acid fluid, except in the axillary and perhaps pubic regions. The mass of the animal frame is thus placed between two great envelops, the one alkaline, and the other acid, meeting only at the mouth, nostrils, and anus. This arrangement has been shown by Donné* to be quite competent to the evolution of electricity, and accordingly he found that if a platinum plate connected with the galvanometer be held in the mouth, whilst a second be pressed against the moist perspiring surface of the body, the needles will instantly traverse, just as they did in the experiment I have just shown with acid and alkali. The current thus detected by Donné at once explains the cause and confirms the accuracy of the celebrated experiment of Professor Aldini, in which he excited convulsions in a frog by holding its foot in the moistened hand, and allowing the sciatic nerve to touch the tongue. His curious experiment with the head of an ox admits of a similar explanation (532).

543. Within the last few months, the results of some researches of Liebig† have rendered it very probable that a large proportion of the electricity of muscular structures is owing to the mutual reaction of an acid and alkaline fluid. The blood, in a healthy state, exerts a decided and well marked alkaline action on test-paper: now it is remarkable that although a piece of muscular flesh contains so large a proportion of alkaline blood, still that when chopped up, and digested in water, the infusion thus obtained is actually acid to litmus paper. This curious circumstance is explained by the fact announced by Liebig, that although the blood in the vessels of the muscle is alkaline from the tribasic phosphate of soda, yet the proper fluids or secretions of the tissues exterior to the capillaries is acid from the presence of free phosphoric and lactic acids. Thus in every mass of muscle we have myriads of electric currents arising from the mutual reaction of an acid fluid exterior to the vessels on their alkaline contents. Whatever may be the ultimate destination of this large quantity of electricity, it is at least remarkable that a muscle should be really an electrogenic apparatus. We have thus two sources of the electricity of muscles—the effects of metamorphosis of effete fibres on the one hand, and on the other the mutual reaction of two fluids in different chemical conditions. It is certainly curious thus to find a muscle, an organ long regarded as the motor apparatus of the bony levers of our frames, invested with new properties. In the course of twenty-four hours, a considerable proportion of watery vapor exhales from the surface of the body. This has been variably estimated, and in all probability is liable to great variation, but from thirty to forty-eight ounces of water may thus be got rid of from the system. It is more than probable that the evaporation of this amount of fluid is sufficient to disturb the electric equilibrium of the body, and to evolve electricity of much higher tension than that set free by chemical action (386). Evaporation may thus probably account for the traces of free electricity generally to be detected in the body by merely insulating a person and placing him in contact with a condensing electrometer. Pfaff and Ahrens generally found the electricity of the body thus examined to be positive, especially when the circulation had been excited by partaking of alcoholic stimulants. Hemmer, another observer, found that in 2422 experiments on himself, his body was positively electric in 1252, negative in 771, and neutral in 399. The causes of the variations in the character of the electric condition of the body admit of ready explanations in the varying composition of the perspired fluid. For if, containing, as it generally does, some free acid, it by its evaporation would leave the body positively electric (386), whilst it merely contains neutral salt, it would induce an opposite condition.

* Becquerel. Traité de l'Electricite, vol. iii.
† Comptes Rendus de l'Academie, Jan. 18 and Feb. 8, 1847.

544. Independently of combustion, chemical action, or evaporation, the mere contact of heterogeneous organic matters is competent to disturb electric equilibrium. Thus a pile of alternate slices of muscular tissue and brain, with pieces of wet leather interposed, has been found by Lagrave to evolve electricity; and Dr. Baconio, of Milan, has shown that a few alternations of slices of beet-root and wood of the walnut-tree were capable of setting free sufficient electricity to excite convulsions in a frog when conveyed to its muscles by means of a conductor formed of a leaf of scurvy grass. Matteucci has thrown out the suggestion, that the organization of a muscle is possibly such as thus by heterogeneity of structure to account for the development of electricity; he considers the analogy between the voltaic arrangements and the constitution of muscle to be complete, if we conceive the zinc, or oxydizing plate, to be represented by the true fibre, the platinum, or conducting plate, by the sarcolemma, and the exciting fluid by the blood.

545. Secretions and nervous agency have always been the favorite phenomena which electricity has been called in to explain, and with some considerable appearance of probability. Dr. Wollaston, thirty-six years ago, first suggested from the re-solution of salts into their elements under the influence of feeble currents, that secretion depended essentially upon the electric state of the secreting glands; he thus regarded the kidneys as constituting the positive and the lever the negative electrodes of the electric apparatus of the body. A curious anecdote is related of Napoleon, who is said by Chaptal to have remarked, on seeing the voltaic battery of the French Academy in action, "*Voilà, docteur, l'image de la vie; la colonne vertebral est le pole, la vessie le pole positif, et le foie le pole negatif.*" We must admit that a greater *hiatus* exists in every argument which assumes that nervous force and electricity are identical, from the fact that delicate as are our tests for this agent, it has never been actually detected traversing the nerves. It has indeed been stated, that on connecting needles plunged in the nerve of a rabbit with the galvanometer, and exciting the muscles of the limb to contract, currents have been detected. Other observers of high repute have stated that a steel needle plunged in a nerve becomes magnetic during the contraction of the muscle it supplies. Both these statements have been rigidly tested, and have been found utterly unsupported by the results of careful experiment.

546. There is, in connection with this hypothesis, a most interesting and important observation of Professor Matteucci, to whose ingenuity and patience we are so largely indebted; this philosopher introduced a plate of platinum into the stomach of a living rabbit, placed another on the liver, and connected both with a galvanometer; the needles instantly traversed an arc of 20°, proving the existence of a powerful current between the liver and stomach. This, it may be observed, shows the existence of a *current*, but does not prove whether it is to be regarded as an effect or a cause of the chemical changes alluded to, for it has been already shown, that when an acid and alkaline fluid are separated by permeable structures, they actually develop a current of electricity; and as the stomach contains an acid, and the liver an alkaline secretion, this might afford an explanation of the current observed by Matteucci; and had the experiment ended here, this plausible objection would have been a fatal one. But the nerves and vessels passing into the abdomen were divided above the diaphragm, and in an instant the needles of the galvanometer were deviated to 3° instead of 20°; and on cutting off the head of the rabbit by a sudden blow, even this little deviation nearly completely vanished. Nothing could be more conclusive than this experiment in proving that the electric current was the cause, not the effect, of the chemical metamorphosis of the saline ingesta, whose decomposition furnished acid to the stomach and alkali to the liver. How this current is excited is unknown,

although it can hardly be doubted that one of the causes which we have already examined is competent for this purpose; but then there remains the difficulty of pointing out the route taken by the current to reach respectively the liver and stomach, for the pneumogastric nerves, at least in man, cannot, from their anatomical distribution, explain this.

547. Sir John Herschel has beautifully expressed the possible relation between galvanic electricity and the *vis nervosa*, and hints at the brain being either the organ of secretion, or at least of the application of this agent; adducing in illustration the dry piles, as they are termed, of De Luc and Zamboni (431), and remarks, that "if the brain be an electric pile constantly in action, it may be conceived to discharge itself at regular intervals, when the tension of the electricity reaches a certain point, along the nerves which communicate with the heart, and thus to excite the pulsation of that organ." By the "dry pile" a ball may be kept in motion for many years, without any obvious waste of power, and some analogous arrangement would constitute the most constant and economic *primum mobile* of a moving organ which the resources of limited human reason can suggest. Dr. Arnott has also hinted at some such cause being the active agent which keeps up the regular pulsations of the heart.

548. It would be quite out of place in a work intended for the general student to enter into any consideration of the interesting but strictly physiological inquiry of the relation existing between nervous agency and electricity. It may be sufficient to state, that although forces are most certainly not identical, still there is a vast amount of evidence which supports the idea that they bear to each other the relation of cause and effect. In the lectures I had the honor of delivering before the Royal College of Physicians* of this year (1847) I entered as fully into this question as our present state of knowledge permitted, and to those I would refer the student for further information.

549. The vital functions of vegetables appear to be frequently attended with a disturbance of electric equilibrium, sufficient to evolve even sparks, at least if we are to believe reports on this subject. Pouillet has satisfactorily proved that electricity is evolved during germination, and Dr. Donné has shown that currents may be detected by means of a delicate multiplier, in all ripe fruits, passing between their bases and apices.

From a few observations made by myself on this subject,† I arrived at the following conclusions:—

1. The great improbability of vegetables, on account of their feeble insulation, ever becoming so charged with electricity as to afford a spark, and the probability of those luminous phenomena said to be exhibited by some plants, depending on other sources than on electricity of tension.

2. That electric currents *of very feeble tension* are always circulating in, and exerting their influence upon, vegetable tissues in every stage of their development.

3. That electric currents are developed during germination, and assist in producing the important chemical changes proper to that process; and that by causing the seed to assume an oppositely electric state, we retard or check its development.

* Reported in the London Medical Gazette for May, 1847.
† Magazine Nat. Hist., N. S., I. 296.

NOTE.

On the subjects treated of in this chapter, the student should refer to Becquerel, Traité, vol. iv.; and to the first volume of Müller's Physiology. The second volume of the Traité complet de Physiologie, of Tiedemann, contains some interesting information on this subject; as also Part v. of section vi. Müller's Physics.

CHAPTER XXI.

UNPOLARIZED LIGHT.

(THEORETICAL CONSIDERATIONS AND CATOPTRICS.)

Theories of light, 550. *Undulatory hypothesis*, 551—555. *Velocity of light*, 556. *Luminous and opaque bodies*, 557. *Photometry*, 559. *Colors*, 560. *Light evolved from every point*, 561. *Rays*, 562. *Modifications of light*, 563. *Law of reflection*, 566. *Ratio of incident to reflected light*, 567. *Specula or mirrors*, 568. *Reflection from plane mirrors*, 569. *Images formed by*, 570. *Series of, produced by two specula*, 571. *Reflection from concave mirrors; Focus*, 572—574. *Reflection from convex surfaces*, 575. *Caustics by reflection*, 576. *Formation of images by concave mirrors*, 577—*by convex mirrors*, 578.

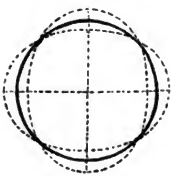
550. SOME doubt and obscurity still remain over the actual nature of light, notwithstanding the innumerable observations that have been made upon it. Passing over the theories, or rather vague ideas, of the ancients, we find three different hypotheses have, in modern times, attracted most notice. The first, and till within the last few years almost universally adopted, was that of Newton; according to whom, light consists of an emanation of infinitely minute particles of matter, thrown off from the sun and other self-luminous bodies, with an enormous velocity, and capable of exciting similar emanations from bodies upon which they impinge, and by which such bodies are rendered visible. The second theory, being that toward which philosophers of the present day generally incline, is a modification of one proposed by Descartes, and adopted by Huygens, Euler, and our late talented countryman, Dr. Young. This hypothesis regards light to be the result of undulatory or oscillatory movements, in the ethereal or imponderable medium, filling up the interstices existing between the molecules of ponderable matter, and extending into space, beyond the confines of our atmosphere. This undulatory theory, as it is termed, is capable of affording a ready solution to certain phenomena, to which the Newtonian hypothesis of emission is, at least at present, to a great extent inapplicable, and, on that account, has received the support of most philosophers of the present day. The third theory, proposed by Oersted, regards light as the result of a series of electric sparks: this has met with but few supporters.

551. According to the undulatory theory, the evolution of light is supposed to be produced by the oscillations of the universal ethereal medium, existing in the interspaces between the atoms of every material substance, and extend-

ing beyond the confines of our atmosphere into infinite space, in the same manner as sound is produced by the vibrations of the denser medium, or air, constituting our atmosphere. The movements thus excited in the eminently subtle and elastic medium, or ether, are readily communicated to what is ordinarily termed a vacuum, but which is really filled with this imponderable matter, as well as to transparent bodies, by causing, in all probability, their particles, as well as those of the insterstitial ether, to assume an oscillatory movement. The ethereal medium contained within the interstitial spaces of transparent bodies is less elastic than that contained in vacuo, and this elasticity appears to diminish with the increase of the refractive power of the substance. The remarks already made on the vibrations of solids (77), and the undulatory or wave-like motions of elastic (206) and non-elastic fluids (172), will render our conceptions of the nature of analogous movements in the eminently elastic non-gravitating medium called ether more easy. Indeed, it is necessary to add but little to the description already given of the wave-like motions assumed by air under certain circumstances, remembering of course that the excessive elasticity and tenuity of this ether permits it to assume the peculiar movements under consideration with almost inconceivable facility and rapidity.

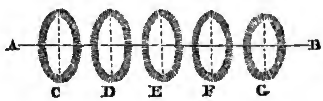
552. On the impression of any applied force each particle of ether, which is assumed to be spherical, oscillates laterally rather than undulates. So that it becomes alternately extended and depressed at its poles and equator, as in the case of the elastic ball of ivory before described (17). In thisla teral oscillatory trembling motion of the particle of elastic fluid, its extension in one direction corresponds to the phase of elevation of a wave of water (172); and its phase of contraction, in the same direction, to the depression of the same wave. Thus, the movements of luminous ether are rather trembling, or oscillatory, than undulatory. And such movements become communicated to distant particles without the intermediate ones becoming moved from their places, in a manner similar to that in which an impulse commucated to the first of a row of ivory balls acts on the terminal one, and causes it to assume motion (76), the intermediate balls remaining unmoved.

Fig. 273.



553. If light be propagated from a luminous body A towards B, its emanation from one point to the other will be effected by all the particles of ether lying in its path, assuming an oscillatory or undulatory movement. The par-

Fig. 274.

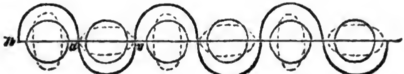


ticle of ether at C will first commence to oscillate, contracting and dilating alternately at its two diameters as shown above; this motion will be propagated to D, thence to E, and so on. These motions of the ethereal particles will thus cause the whole line AB to become luminous.

554. A little reflection will show that the ultimate effect of these movements of contiguous particles will produce as a result a progressive vibration (79); the vibration or pendulation of each particle being perpendicular to the

path of the resultant ray. Now it is obvious that in the above diagram the particle C will complete its vibrations at the instant D commences its motion, and so on with the others; thus CEG and DF will be vibrating cotemporaneously in the same direction, whilst CD, EF, and G will move in opposite directions. To compare these movements with the different phases of a wave of water (172), let us take six vibrating atoms of ether as before, AB, CD, FF. Now ACE will be dilating in one direction whilst BDF will be dilating in the opposite. Hence AB, as well as CD, EF, will be in opposite phases at the same time, and their motions may be compared to that of a progressive undulation of a rope (78), as shown by the curved lines in the figure; the distances *w v*

Fig. 275.



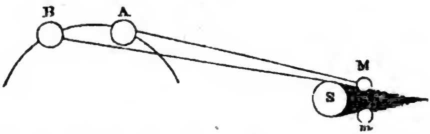
will be equal to the length of a wave or undulation, whilst *wa* and *av* will be equal to half a wave. We further learn that all the particles of ether in the path of a ray of light which are at the distance of 1, 2, 3, 4, &c., waves are undulating in the same, whilst thus ½, 1½, 2½, 3½, &c., waves distance are undulating in the opposite direction. In the consideration of luminous undulations, they must be regarded as propagated in all directions in an infinite series of planes round the luminous body, just as has been already explained in the case of aërial undulations (206).

555. The waves of light, like those of sound (219), are thus transmitted in every direction, extending on every side of the luminous body, with an intensity inversely as the square of the distance (222). Whilst sonorous vibrations are conveyed to the ear, through the atmosphere, by the particles of air composing the latter assuming a similar wave-like movement, the luminous body, as the sun, or a lamp, by exciting an analogous undulatory movement in the universal ethereal fluid, (which becoming conveyed by contiguous particles, eventually reach the eye,) communicates the sensation of light to that organ, in the same manner as sonorous vibrations convey the sensation of sound to the ear. Thus, the cessation of undulations, or repose of the ether, produces darkness; as the absence of similar movements in the air produces silence. It has been objected to this theory, that if true, light ought to bend round opaque obstacles, in the same manner as the waves of water find their way round fixed obstacles, and be communicated through curved tubes, like sound, and consequently that no true shadow ought to exist. These objections, however, are more apparent than real; for, taking the case of sonorous vibrations, we find that they do not bend round obstacles with facility, and that an acoustic shadow does really exist. Thus the sound of a rapidly moving carriage becomes less distinct as it turns the corner of a street; and sounds passing through water are still more readily obstructed (229). The existence of an acoustic shadow may be better shown by vibrating a tuning fork, and holding it about six inches from the ear; suddenly interpose a piece of card between the latter and the sounding body, instantly the tone will disappear, and on withdrawing the card will again become audible, and so on. In the case of curved tubes, we know that whilst sonorous undulations are readily transmitted through them, those of light are completely excluded; for no one can see through a bent brass pipe. But, in this case, it must be recollected, that the sides of the tube, whilst they

are sufficiently smooth to *reflect* sound and to assume sonorous vibrations, they are infinitely too rough and too inelastic to reflect, or to assume undulatory movements sufficiently rapid to produce light. There is no difficulty in seeing objects through a tube bent twice at right angles, providing four plane mirrors are properly placed in its interior; and it is certainly at least possible, that bodies are not visible through bent tubes, because the opaque substances of which they are composed stifle and check any luminous undulations (551) that may enter them. Lastly, whilst sonorous undulations are thus shown to pass round inelastic obstacles with extreme difficulty, those of light are capable of, to a certain extent, passing round the edges of opaque bodies, and entering their shadow, as shown in the phenomena of *inflection* or *diffraction* (634).

556. Luminous undulations, (or, in other words, light,) are propagated from the sun, through space and to the surface of our globe, with an enormous velocity, at the rate of about 191,515, or, in round numbers, 192,000 miles per second; and this motion is the same for light evolved from the most distant fixed star as for that from the nearest self-luminous body. This rate of propagation of light was first discovered by Olof Roemer, a Danish astronomer, in the year 1676, when observing the occultation and emersion of the satellites of Jupiter. He found that when the earth was directly receding in its orbit from that planet as from A to B, the emersion of its first moon *m*, from its shadow at M, occurred 15 seconds later than the calculated time. To

Fig. 276.



make this clear, let us suppose that an observer on the earth at *a*, watches the immersion of the satellite *m* into Jupiter's shadow; now it is known from the period of its entire revolution, that it ought to emerge at *m* in 42 hours, 28 minutes, 35 seconds; but if at the end of that time the observer again looks, he will have to wait 15 seconds later before he will observe the emergence of the satellites at *m*. The reason of this is that in 42h. 28′ 35″, the earth will have moved in its orbit from A to B, a distance of 2,880,000 miles, and the fifteen seconds were occupied by the light of the emerging moon to overtake the earth. In like manner when in the opposite side of its elliptic path, the earth advances towards the planet, the emergence of its moons will appear to take place proportionably earlier. The light of the sun consequently requires 8 minutes 13 seconds to reach the earth, whilst that of the planet Herschel occupies 2 hours 40 minutes in traveling to us. At least six years are required for the light of the nearest fixed star to reach us, and it has been supposed that there may exist fixed stars so distant that their light may never yet have reached our planet, and consequently they remain invisible to us. Were a new fixed star at the distance of Sirius to be created, we should not be aware of it until six years had elapsed, and were Sirius itself to be annihilated, it would still appear to us to exist for as long a time after its destruction.

557. All bodies may be divided into those which are self-luminous, i. e., capable of exciting luminous undulations of themselves, as the sun, or a lighted lamp; and those which are *opaque*, and only become luminous in the presence of the former: thus the moon and planets are opaque bodies, and

are luminous only in consequence of the presence of the sun about which they revolve. A great number of bodies possess the property of intercepting the passage of light, and thus producing a shadow by obscuring the substance from which they intercept the luminous undulations. These shadows are, in general, bounded by right lines, or present the same figure as the sections of the intercepting bodies, in consequence of the difficulty of luminous undulations extending round obstacles. Such bodies as permit light to pass through them are termed *transparent*, in opposition to those which intercept it, constituting *opaque* substances.

558. Non-luminous bodies become luminous in the presence of self-luminous substances—either, if sufficiently smooth, by reflecting the undulatory movements back into the ethereal medium, or by having vibrations excited in the imponderable matter contained therein, or perhaps even in the material structure of the body itself, which, if sufficiently rapid, become communicated to the surrounding ethereal atmosphere. Thus then bodies are not rendered visible by anything giving off from a luminous source, and impinging upon them; but, by the undulatory movements arising from the alternate condensation and expansion of ether communicated to contiguous particles, and thence to the opaque body, whose included imponderable matter assumes a similar movement, and thus the body becomes in its turn a source of fresh luminous undulations.

559. The intensity of illuminations of any body in the presence of a source of light will depend upon its distance from that source, and obeys the general law of radiant forces as attractions (21), *the intensity of the light diminishing as the square of the distance of the luminous body.* Thus, if a single candle illuminates a body to a certain extent at the distance of a foot, it would require four candles at a distance of two feet, and of nine at three feet, to produce equal illumination.

It is often important to be able to compare the intensity of two sources of light, and for this purpose instruments termed photometers have been contrived. Of these the most perfect is that contrived by Prof. Wheatstone, consisting of a bead of silvered glass rapidly moving in two parallel lines by means of a very simple and ingenious mechanical contrivance. In this way the two lights to be compared are reflected as two luminous points apparently but a fraction of an inch apart. Then altering the distance of one of the lights until the luminous spots on the bead are of equal intensity, and squaring this distance from the photometer, their different illuminating powers are readily discovered. Some approach to a comparative measurement of it, may be obtained by ascertaining the squares of the distances at which any two sources of light, as two candles, require to be placed, to cast upon a wall, shadows of a rod of wood or metal of equal intensity; these numbers will be to each other in the ratio of the intensity of the light evolved from the two candles. The illuminating power of any sources of light will of course not only depend upon the intensity of its light, and its distance, but upon the extent or area of its luminous surface. According to Dr. Wollaston it would require 20,000 millions of such stars as Sirius, or 5,563 wax candles at the distance of a foot, to produce a light equal to that of the sun.

560. If the surfaces or internal structure of substances be arranged in a certain manner, the luminous undulations produced by it in the presence of a self-luminous body will communicate to the eye the sensation of *white* light; but if it be so constructed as to check all the luminous undulations which act upon it, it cannot become the source of a fresh set of analogous movements, and is said to be *black*. We know that in the Æolian harp the strings assume different states of vibration, and evolve corresponding sounds, when acted upon by a current of air, according to the diameter and tension of the cords

(288); the tightest and thinnest string evolving the sharpest, the loosest and thickest the lowest note. In a similar manner are the undulations arising from any source of light supposed to be affected by the physical structures of bodies, by which the elastic ethereal medium contained in some assumes undulatory movements analogous to the tightly-stretched cord in the Æolian harp, and thus communicate to the eye the sensation of violet or purple light; whilst the particles of ether contained in other substances under similar influence, oscillate with a less degree of velocity, and convey the idea of *red*, on reaching the eye. The rapidity of the undulatory movement assumed and propagated by colored bodies does as infinitely exceed that of sonorous vibrations as the density and elasticity of ether do that of the air. Thus, whilst to evolve red light, a body must communicate to ether about 477 millions of millions, and to evolve violet, not less than 699 millions of millions of undulations in a second; the lowest note, or C of the fourth octave from the base (241), is produced by 258, and the highest, or C of the next octave, by but 516 vibrations in a second of time. It has been calculated that if a string of the proper length to produce a sound when vibrating, corresponding to the middle C of the piano, were bisected 40 times, it would, supposing it was still possible to make it vibrate, evolve not a sound but a *yellowish-green light*. The vibrations of a cord increasing in rapidity with the diminution of its length.

Colors are consequently no more *innate* or abstract properties of bodies than any particular sounds or notes are; the latter varying with the tension, length, and thickness, of the substances, and the former with certain, perhaps analogous, vibrations of physical structure.

561. Luminous undulations are produced by every portion of a body (535), and vary in their rapidity with the color of the substance. If a small hole be made, or, still better, a convex lens be fixed in one end of a wooden box, blackened internally, and it be presented towards any object or landscape, an inverted image will be painted upon a piece of white paper, fixed at the opposite end, and presenting the very same hues as the object of which it is the image.

562. A ray of light on the undulatory hypothesis, is a right line extending from the luminous body to the limit of the sphere of undulation; and consequently, in the direction in which the body is visible (653). To such rays the undulations producing them are perpendicular; they therefore must be considered as merely expressing the direction of *an effect*, and not, as on the Newtonian hypothesis, as causes or sources of light.

563. When a ray of light falls upon the surface of any substance, it may undergo one or more of the following modifications: A, It may be *reflected* back into the medium in which it was moving (566); B, it may pass into the substance and be *refracted* (579), still retaining its original characters; or may, C, be divided into two portions, each possessing distinct physical properties (650); D, a ray may become absorbed by having the undulations producing it checked (615); or may, E, excite a fresh set of undulations, and consequent rays, on the surface of the substance, thus rendering it visible; F, it may also by meeting with a second ray, have its intensity modified by their mutual *interference* (630); or, G, during its refraction, or reflection, or partial absorption, acquire new properties, characteristic of polarized light (661); and lastly, have the rapidity of the undulations producing it so affected as to give rise to the phenomena of colors (605).

564. When luminous rays proceed from a very distant body, as the sun, they may be regarded as *parallel;* when they are given off from a point extending as they proceed, they are termed *divergent;* and when they gradually

approach each other, as after being acted upon by a concave mirror or convex lens, they are said to be *convergent*.

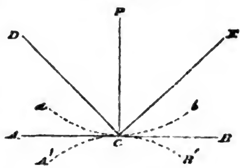
565. When parallel rays fall upon a plane surface, their illuminating power varies with the angle they describe with it the most perfect illumination being produced when they fall perpendicularly upon it.

Fig. 277.

Let the parallel rays *a*, *b*, *c*, *d*, *e*, *f*, fall upon a surface OP, and it is obvious they will all be effectual in illuminating its surface; but if OP be inclined to PR, but four of the six rays will impinge upon it, and it will be proportionably less illuminated. Hence the law that the intensity of the light will be *as the sine* (RS) *of the angle of incidence of the rays.*

566. Whenever a ray of light falls upon a plane polished surface capable of reflecting it, it obeys the same law as that of moving elastic bodies (62), the angle of incidence and reflection being equal. Thus, let AB be the surface of a plane mirror, and DC a ray incident upon it: draw the perpendicular line PC, and DC will be reflected in the direction CE, forming the angle PCE, equal to the angle PCD; the latter being the angle of *incidence*, and the former that of *reflection*. If instead of the ray being incident on a plane, it had encountered a curved surface, it would have obeyed the same law and be reflected at the same point as from a plane, which would be a tangent to the curve at that point. Thus, if the ray DC were incident upon the concave surface *ab*, or the convex one A′B′, it would still be reflected from C in the same manner as if it were incident upon a tangent to either curve at C or ABC. The lines DC, PC, and EC or the direction of the incident and reflected ray, will always be in the same plane with the perpendicular.

Fig. 278.



567. A considerable proportion of the luminous undulations become checked on impinging upon reflecting surfaces. Thus the intensity of the reflected light is never equal to that of the incident; this loss diminishes with the obliquity of the incidental rays. M. Bouger has given the following table of the proportion of incidental to reflected rays at different angles from the surfaces of water and of glass; the number of incidental rays being supposed to be 1000:

Angle of Incidence.	Surface of water.	Surface of glass.
85	501	549
80	333	412
75	211	299
40	22	34
20	18	25
0	18	25

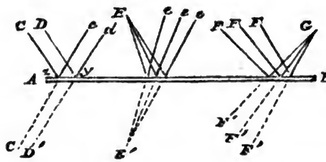
Even when reflected from the surfaces of the most perfectly polished metallic mirrors, much light is lost; thus from the surface of mercury at an angle of incidence (566) of 78° 5′, but 754 rays out of 1000 become reflected. When the reflector is diaphanous, as a glass plate, more light is reflected from

the second than from the first surface, and this proportion is increased by coating the back with some resinous cement, or, still better, metallic amalgam; the vividity of the reflection from the second surface then completely eclipses that from the first. Thus, in the common looking-glass, the bright images seen in it, are reflections from the second or coated surface.

568. Any substance possessing some regular form, and sufficiently polished to reflect light, is termed a *speculum* or *mirror*. These are made of various materials, as of polished metal, or of glass, covered at the back with an amalgam of tin. Mirrors are made in various forms; of which, the *plane* consists of a level surface of polished metal or glass; the concave, presents a hollow surface like the inside, and the convex, a projecting superficies like the exterior of a watch-glass. Besides these, mirrors have been constructed in the form of certain conic sections, as the ellipse, hyperbola, and parabola.

569. Rays of light falling upon the surface of a plane mirror, as a looking-glass, always retain their original rectilinear direction after reflection.

Fig. 279.



Let AB be the surface of a plane polished mirror, and CD be *parallel* rays incident upon its surface, they will be reflected in the direction *cd*, according to the law already mentioned (566). *Diverging* rays proceeding from E will, after incidence, continue to diverge in the direction *eee*, and *converging* rays, as FFF, will continue to converge after being reflected from AB towards the point. In all these cases, as objects appear to the eye to be situate in the direction of the rays which eventually reach that organ, to spectators placed at *cd*, *eee*. and G, the rays CD, E, and FFF, will appear to have come from behind the mirror AB in the direction of the dotted lines C′D′, E′, F′F′F′. In all these cases, the effect of reflection is to throw the *apparent* origin of the rays to the opposite side of the mirror.

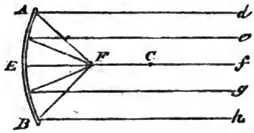
570. As all bodies become under certain circumstances the source of luminous undulations proceeding from every point of the object, and possessing a degree of rapidity corresponding to the colors of the substance; or, in conventional language, all bodies evolve rays of the same colors as themselves; it follows, that any object placed at CD (569), will appear to a spectator placed at *cd*, to be in the direction C′D′, as the rays evolved from the object will, after reflection on AB, proceed in the direction *xc*, *yd*, and consequently appear to the observer to have been given off from some object situated at C′D′, as far behind AB as CD is before it. This representation of the object so vividly presented to the idea is termed an *image*, and precisely resembles in tint and outline the real object to reflection from which it owes its origin.

571. When two plane mirrors (568) are placed parallel to each other, and any object be situate between them, a long and almost infinite series of images will be seen in each mirror, from the object and its image in one being reflected by the other, and so on, until these figures appear so remote as to be invisible. If the two reflecting surfaces be inclined towards each other at any angle, the images of an object placed between them will appear to lie in the

circumference of a circle of which the mirrors represent the radii. This is the principle of the well-known kaleidoscope invented by Sir David Brewster: in this elegant instrument, the images of the objects placed between the reflectors are seen most beautifully arranged when the latter form an angle, which is an aliquot part of a circle. Thus, if the angle between the mirrors be 60°, the images of the object will appear arranged in a circle, and a hexagonal figure will be produced; for if the angle be a measure of 180, the number of images formed will be equal to 360 divided by that angle.

572. When parallel rays of light, as when emanating from a distant body (564), be incident upon a *concave* reflecting surface, they are reflected as if from a series of planes, tangents to that surface, and are made to converge. Thus if AEB be a concave mirror, of which C is the geometrical centre, and parallel rays, as *defgh*, be incident upon it, they will be reflected according to the general law of reflection (566), and consequently be made to converge towards a point F, situate midway between the centre C and the point E, F being consequently equal to half the radius of the concavity of the mirror.

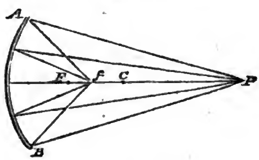
Fig. 280.



It is obvious that all the luminous undulations producing the rays *defgh* will be reflected towards F, and, arriving at that point at the same instant, will cause any particles of ether there situated to be acted upon and agitated with an intensity corresponding to the united force (534) of all the undulations propagated from the reflecting surface. On this account all the light and heat belonging to the incident rays will become concentrated at F, and luminous and calorific effects of corresponding intensity will be excited on any body placed on that spot. This point is hence termed the *focus* or *fire-place* of the mirror AEB *for parallel rays;* the distance FE being termed the *principal focal distance, or focal length* of the mirror.

573. If *diverging* rays be incident upon a concave mirror they will be conveyed to a focus which differs from the point F in the last figure, in being situated nearer the centre of the mirror's concavity. Thus, if rays diverging from a luminous source, as a lighted candle P, be incident upon a concave mirror AB, they will be reflected, according to the general law, to a focus *f* much nearer C than the point F, or focus for parallel rays (572). If then the candle P be placed at *f*, the luminous rays will be reflected by the mirror to a focus at P; hence P and *f* are termed *conjugate foci*, for either becomes the focus to a radiant point placed at the other. Whereas, if the source of light be placed at F, the rays will be reflected in a parallel direction, and never meet at a focus. If the candle or other radiant point be placed nearer the mirror than *its principal focus*, its rays will be reflected, not parallel but divergent, as though they were evolved from some point placed behind the mirror. The conjugate focal distance for diverging rays may be found by the formula $\frac{d+r}{2d\times r}$ in which d corresponds to the distance of the source of light from the mirror, and r to the radius of curvature of the latter.

Fig. 281.



574. When converging rays are incident on a concave mirror, they will be

reflected to a focus nearer the mirror than the principal focus of F (572), the reverse consequently of diverging rays. These rays, falling on a mirror, appear to converge towards a point situated behind it, and their focus may be found by the following formula, in which c corresponds to the distance of the point of convergence from the mirror, d and r retaining their former values

(573) $\frac{c \times r}{2d + r}$.

575. When luminous rays are incident upon convex mirrors, they are acted upon in a manner opposite to that which they were by concave reflecting surfaces; for whilst a concave reflector lessens the divergency, and increases the convergency of all incident rays, a convex one increases their divergency and diminishes their convergency. Thus, if parallel rays *abcde* (fig. 282) be incident on the convex mirror AB, of which C is the centre of convexity, they will be reflected, according to the general law (566), in the direction $a'b'd'e'$, as if they had proceeded from a point F placed behind the mirror, which thus becomes the *virtual*, *apparent*, or *negative* focus of the reflected rays. The *focal distance* F for parallel rays is one-half of the radius of the convexity of the mirror, and always situated behind the mirror, whilst in *concave* reflectors it is before it (572). In the case of diverging rays, the focal distance will be less, and for converging beams greater than F.

Fig. 282.

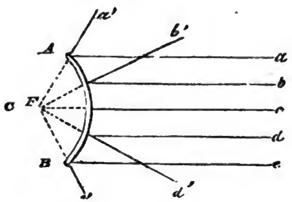
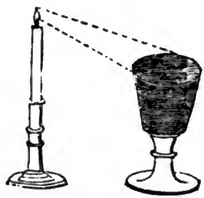


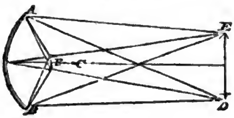
Fig. 283.



576. When luminous rays are incident upon a curved reflector, every point of its surface may be considered as an infinitely minute plane mirror (568), reflecting all the rays falling upon it. When a series of rays fall upon a surface thus constituted, they after reflection mutually intersect, and these points of intersection constitute a curved line, termed a *caustic*. To exhibit this caustic curve by reflection, nearly fill a glass tumbler with milk (fig. 283), or fit a circular piece of card into it about half an inch from the top, and, exposing the concavity of the glass to the sun or a candle, a brilliant double curve will be represented on the surface of the milk, or piece of paper.

577. Images are formed by spherical mirrors in the same manner as by plane ones (570), and differ from those produced by the latter instruments in being of a different size from the object. Thus, if rays be supposed to emanate from a distant body, they will, on being incident on the concave mirror AB, of which C is the centre of concavity, be reflected to a focus at F, a little beyond the principal focus (572), and there paint an image of the object ED, diminished in size, and, from the altered relative position of the rays after reflection, inverted in direc-

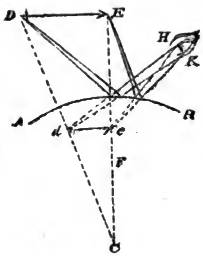
Fig. 284.



tion. The image F will be extremely vivid from its being virtually illuminated by all the luminous rays incident on the mirror. The magnitude of the image F will be found to bear the same relation to ED as the distance of F from the mirror does to that of the object from it. If an object be placed at F, its image will be painted on a screen placed at ED, diffused over a large space, and consequently magnified.

578. In the case of convex mirrors, the images are in an erect position, much diminished in size, and behind the reflecting surface as in the plane mirrors. For if an object DE be placed before a convex mirror AB, whose negative focus

Fig. 285.



is at F, the luminous rays will, after incidence on AB, be reflected diverging; and being seen by a spectator at H, they will appear to him as proceeding from an object *de* behind the mirror, and considerably smaller than DE, of which it is merely a diminished image.

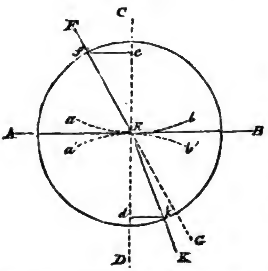
CHAPTER XXII.

UNPOLARIZED LIGHT. (DIOPTRICS.)

Law of sines, 579. *Refraction from dense through rare media*, 580. *Index of refraction*, 581. *Refraction through two media*, 582. *Ratio between refractive index and velocity of undulations*, 583. *Limit to refraction, internal reflection*, 585. *Unusual refraction, mirage*, 586. *Refraction through parallel surfaces*, 588—*through prisms*, 589. *Lenses*, 590. *Refraction through spheres*, 591—*through convex lenses*, 593. *Formulæ for focal lengths*, 594. *Refraction through concave lenses*, 595—*through menisci and concavo-convex lenses*, 597. *Caustics by refraction*, 598. *Formation of images by lenses*, 590. *Magnifying power of convex lenses*, 600. *Spherical aberration in lenses*, 603—*in mirrors*, 604.

579. So long as a ray of light traverses a uniform medium, it continues its path in a right line, which it also preserves when it is incident on a diaphanous substance in a direction perpendicular to its surface. But if it be incident in an oblique direction, it becomes somewhat bent, or *refracted*, out of its original course: this bending, or *refraction*, not being, to the same extent in every substance, as the direction of reflection (566) is, but varying considerably in different forms of matter. Thus, let AB be the surface of a refracting medium, as water; draw CED perpendicular to it, and let FE be a ray incident on AB at E; a certain portion will be reflected (566), the remainder entering the medium, and instead of following the direction EG, will be refracted or bent towards D in the direction EK. The line FE will, therefore, represent the incident, and EK the refracted ray; FEC will be the angle of incidence, and DEK the angle of refraction. Draw the lines *cf dk;* the former will be the sine of the angle FEC, and the latter that of the angle DEK, and they will be to each other in a constant ratio for each refracting substance: the sine *dk* being to the sine *fc* as unity is to the refracting power of the medium, or in the case of water as 1 to 1·336; the latter being the *index of refraction* of the medium AB, and is found by dividing the sine *fc* by the sine of refraction *dk*. From this reasoning, we see that the incident and refracted rays must always be in the same plane, but on different sides of the perpendicular CED.

Fig. 286.



580. As the visibility of any two points is mutual, it follows that a ray of light, KE (579), passing from a refracting medium, ADB, as water, will, on reaching the surface, AB, of a rarer one, be refracted into the direction EF. In this case, as KE is the incident, and FE the refracted ray, the line *fc*, which is now the sine of refraction, is greater than the line *dk*, or sine of incidence, the reverse of the former case, and *fc* will be to *dk* as 1·336 is to one. The index of refraction for a ray passing from a denser into a rarer medium, or, in this case, from water into a vacuum, may be found by dividing unity by the refracting index of the denser medium, or, $\frac{1}{1\cdot336}$; it is, therefore, equal to the *reciprocal* of the refractive index of the water, or other dense medium.

581. The index of refraction, or, in other words, the refractive power of a medium, varies considerably, being for chromate of lead 2·974, and for air 1·000294, between which limits every intermediate degree of difference exists. It was ascertained by Sir Isaac Newton, that inflammable bodies in general possessed a higher refractive power than other substances; on which account he made the bold suggestion, that the diamond, whose refractive index is about 2·439, consisted of a combustible substance, ("qui ut probabile est, substantia est unctuosa coagulata;"*) a statement whose correctness has been amply demonstrated by the discovery of the true chemical nature of the dia-mond. As a general law, the greater the specific gravity of the body, the more it refracts light passing through it; and the chief exception is found in the case pointed out by Newton, of inflammable bodies; and if allowance be made for the generally lower specific gravities of this class of substances, they will be found to possess a greater *absolute* refracting power than any other bodies. In the following table the index of refraction of several substances, when a ray is incident upon them from a vacuum, is contrasted with their absolute refracting powers:

Name.	Refracting Index.	Absolute Refract-ing Power.	Name.	Refracting Index.	Absolute Refracting Power.
Vacuum . .	1.000000	0.	Alum	1.457	0.6570
Hydrogen . .	1.000138	3.0953	Oil Olives	1.470	1.2607
Oxygen . .	1.000272	0.3799	Oil Turpentine	1.475	1.351
Common Air .	1.000294	0.4528	Castor Oil	1.490	1.148
Nitrogen . .	1.000300	0.4734	Oil of Cloves	1.535	1.309
Ammonia . .	1.000385	0.4734	Crown Glass	1.525-1.534	0.526
Carbonic Acid	1.000449	0.4537	Plate Glass	1.514-1.542	?
Chlorine . .	1.000772	0.4813	Amber	1.547	1.3654
Tabasheer .	1.111	?	Quartz	1.548	0.5415
Fluids in Topaz	1.294-1.31	?	Flint Glass	1.585-1.60	0.7986
Ice	1.309	?	Oil of Cassia	1.641	1.7634
Water . . .	1.336	0.7845	Sulphuret of Carbon	1.768	1.4200
Ether . . .	1.358	2.56			
Alcohol . .	1.372	1.0121	Sapphire	1.794	0.5556
Hydrochloric Acid	1.410	0.5514	Garnet	1.815	0.5423
			Zircon	1.961	0.6054
Nitric Acid .	1.410	0.624	Sulphur	2.148	2.2000
Sulphuric Acid	1.434	0.6124	Phosphorus	1.224	2.8857
Fluor Spar.	1.434	0.3414	Diamond	1.439	1.4566

On looking at this table, it will be found that the absolute refractive power of hydrogen exceeds that of all other bodies, when allowance is made for its low specific gravity. These absolute refractive powers are calculated on the supposition of the ultimate particles of bodies being equally heavy, by dividing the excess of the square of the index of refraction above unity, by the specific gravity of the substance.†

582. When the refracting action of any medium, on a ray entering it from a vacuum, is required, the above table will enable us to find it; but when the direction of a ray passing from one medium to another is sought for, we must divide the index of refraction of the second medium by that of the first, and

* Newton. Optice, sive de reflexionibus, &c., lucis, lib. ii. pars. 3. Lat. red. S. Clarke, London, 1719.

† Newton. Optice, sive de reflexionibus, &c., lucis, lib. ii. prop. 10.

the quotient will give the ratio of the sine of refraction to that of incidence from one body to the other. Thus, if the index of refraction for a ray passing from water into plate glass were required, the index of refraction of the former being 1·336, and of the latter 1·542, we have only to divide the latter by the former number, or $\frac{1\cdot542}{1\cdot336}=1\cdot154$, the required index.

583. Luminous undulations are propagated through media, with a velocity varying with their refractive power; the higher the refractive power of the medium the slower the ray of light moves through it, the velocities through any two media being in the inverse ratio of the sines of refraction; consequently, if during a given time, a series of luminous undulations are propagated through a tube filled with air, of 100 feet in length, a similar series, in the same space of time, will traverse but 75 feet, when the tube contains water.

584. When a ray is incident on a refracting surface, bounded by curved lines, the same law obtains as when incident on a plane. For if AB (579) were replaced by a concave or convex surface, as *ab a′b′*, the ray FE will follow the same course, as if it impinged on a plane, a tangent to the curve at the point of incidence.

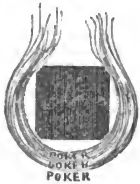
585. From an inspection of the diagram (579), ABC being a rarer and ABD a denser medium, we see that the sine *fc* of the incident is always greater than the sine *dk* of the refracted rays; and if the ray FE were incident at so great an obliquity that its sine would nearly correspond to radius, and, consequently, that the luminous ray could only graze the surface of the medium AEBD, still a considerable portion of the light would really enter and be refracted, as the sine of refraction in a dense medium is invariably less than the sine of incidence. The converse of this proposition is extremely remarkable: for if KE be a ray passing through the dense medium ADB into a rare one ACB, the sine of refraction *fc* will exceed that of incidence *dk* (579). When KE is incident on AB, at such an obliquity that the sine of the refracted ray would correspond to radius, it ceases to pass out of the dense medium, and is *reflected* from the surface AB back into the medium ABD, according to the ordinary law of reflection (566). This sudden conversion of refraction into reflection is extremely remarkable, and affords the only instance of *total* reflection with which we are acquainted; for if the ray be incident in a dense medium on the surface of a rarer one at a sufficient obliquity, it is totally reflected, no light being lost, except from a few undulations being checked by the medium itself. The angle at and within which this *internal reflection* occurs, is termed *the limiting angle* between refraction and reflection. This *limiting angle* may be found by dividing unity by the index of refraction of the substance; and on looking for the quotient in a table of natural sines, the angle corresponding to it is the limiting angle. Thus, a ray cannot pass from water into a vacuum, if the angle of incidence exceed 43°·27′ for $\frac{1}{1\cdot336}=$ sine of that angle: nor can a ray pass from flint glass into vacuum, if the angle exceed 38°·41′ for $\frac{1}{1\cdot60}=6250$, the sine of that angle. The brilliancy of the light thus reflected far exceeds that reflected from the best metallic mirrors. This may be readily shown by nearly filling a wine glass with water, and holding it up, so that the surface of the fluid may be seen from beneath: it will appear like a sheet of burnished silver, from the perfect reflection of the incident light, and no object held above it will be visible if the position of the eye be within the *limiting* angle.

586. When an object is viewed through two media of different refracting powers, very curious results follow. This may be often observed when an object, situated at or near the horizon, be so far from us, that, in consequence of the curvature of the earth, a right line could not connect it with the eye of the spectator, it will be invisible, except under a few remarkable states, con-

stituting the phenomena of *unusual refraction.* For the production of these effects, it is necessary that the strata of atmosphere near the earth should differ considerably in refracting power, either by one portion being more loaded with vapors, or possessing a lower temperature than the other; so that, by the great degree of refraction to which rays passing from the distant object become submitted, they virtually reach the eye in curved lines, and the spectator sees an image of the object in the air, in the direction of a tangent to these curved lines, and inverted, in consequence of the altered relative position of the rays passing between the object and the spectator.

Phenomena of this kind, constituting the *mirage*, or *fata morgana* of the Italians, are occasionally seen in great splendor in the Straits of Messina. In the north of Europe, and in several parts of Great Britain, the mirage has been frequently observed, and is by no means of very rare occurrence on the English coast, in the evenings of hot autumnal days.

Fig. 287.



Some of the conditions for the production of the mirage may be observed by regarding a small object, through the point of mixture of two fluids of different densities, as syrup or alcohol, and water, when images will be seen on a plane higher, and in an inverted direction, with regard to the original object. The same effect may be observed by looking at an object across a red-hot iron, or over a charcoal chauffer; or still better, on a cool day, by regarding a distant wall or tree over the boiler of a steam-carriage. The wall or tree will appear to be divided into several portions, and surmounted by inverted images visible for a considerable space above the source of heat.

587. The transition from partial to total reflection may be beautifully seen in an experiment described by Newton.* Hold an equi-angular prism, in the position shown in the figure, before an open window, in such a manner that a line drawn from the eye may describe an angle of about 40° with the base of the prism. The base ABCD (fig. 288) will appear to be bisected by a curved iris, VV, of a bluish violet color, the space between VVAC appearing of a sombre hue, in which reflection is extremely imperfect; but beyond VV, including the space VBVD, the whole will appear shining with a metallic splendor, the clouds and surrounding objects being depicted upon it with great brilliancy. The iris VV thus divides the space between partial and total reflection.

Fig. 288.

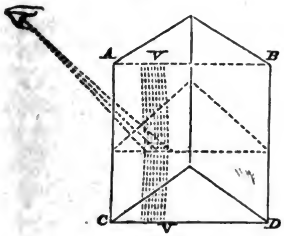
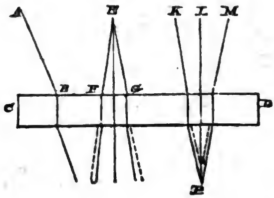


Fig. 289.



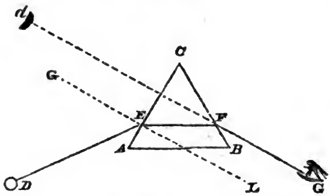
588. If a ray of light be incident upon the surface of a refracting medium, bounded by plane parallel sides, as a plate of glass, it will undergo no change

* Optice, *supra citat.* Lib. ii. exp. 16, p. 159.

of direction, if it describe a perpendicular to the refracting surface; in any other direction it will be refracted according to the laws already detailed. Thus, if AB (fig. 289) be incident on a medium, as a pane of glass, CD, it will undergo refraction, and escape on the opposite side, in a direction parallel to the incident ray. If diverging rays, as EFG, be incident, they will, after refraction, emerge from CD parallel to their former direction, their divergence having become diminished; and if converging rays, as KLM, be incident on CD, and converging to O, they will, after converging from the medium, really converge at P.

589. Prisms are made of glass for optical purposes, with their sides at various angles of inclination. ABC represents one whose sides are inclined to each other at an angle of 60°; CA CB are termed the refracting sides, and AB the

Fig. 290.

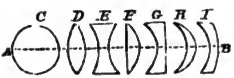


base of the prism. If a ray of light, DE, be incident on the side CA, it will be refracted towards its base if the prism be denser, and towards its apex if rarer, than the surrounding medium. Let the prism be of glass, and draw GEL perpendicular to AC; the ray DE, on entering the prism, will be refracted towards its base, and consequently towards the perpendicular GEL in such a manner, that the sine of the angle GED will bear the same relation to the sine of FEL that the index of refraction of the glass prism does to that of the surrounding medium of air. Hence, in viewing objects through a prism, they always appear to be higher or lower than they really are; for, if an object be placed at D, it will appear to a person stationed at L to be at *d*, because the ray FG, if produced, will reach *d, and objects always appear to be situated in the direction of the rays which eventually reach the eye* (569).

590. Lenses are made for optical purposes constructed of glass, and certain transparent minerals, of various forms. Sections of the principal kinds of lenses are shown in the following figure; and, if these be supposed to revolve round the axis AB, each will describe the particular lens of which it is the section.

The *spherical lens* is a simple sphere of glass, C; the *double convex* D is bounded by two convex surfaces, concave towards each other; the *double concave* E has both its surfaces concave, their convexities being opposed to each other; these two lenses may have both their surfaces of unequal, or of equal curvature. A *plano-convex* lens F is merely half a double convex, one surface being plane, the other curved, as in the latter. A *plano-concave*, G, is a lens having one surface plane and the other concave. The lens H, termed a *meniscus*, has one surface concave, the other convex, and these curves meet if continued; whilst the *concavo convex* lens I has similar

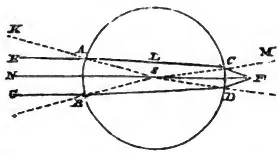
Fig. 291.



surfaces, but they do not meet if produced, as the convex surface has a lesser curvature than the concave side.

591. The course of a refracted ray through a spherical lens may be readily understood; for let ABCD be a sphere of flint glass of a refractive index of 1·60 (581), and let the parallel rays ENG be incident upon it—the ray N, being incident perpendicular to the spherical surface, will pass through without refraction (579). To find the course of the ray E, draw the perpendicular KAS, and produce the line E to C with such an obliquity that the sine of the angle ALS may be to the sine of the angle KAE as 1 is to 1·60; the ray ALC becomes thus bent towards the perpendicular KS. On reaching C, the ray will emerge into a rare medium, and will again suffer refraction, being bent *from* a line MCS perpendicular to the surface at C, at such an angle that the sine of LCS will be to the sine of MCF in the ratio of the refractive index of air, or 1·000294, to that of flint glass, or 1·60. By a similar process, the course of the ray G may be found. The three rays will thus meet at F, which is the principal *focus*, or *focal length* (572) of the spherical lens for parallel rays.

Fig. 292.



On referring to the position of the *conjugate foci* of concave mirrors (573) it will be readily seen that, if diverging rays be incident on the sphere of glass, their focal distance will be beyond F; and if converging rays be incident, their focus will be at some point nearer the sphere than the focus for parallel rays, or F.

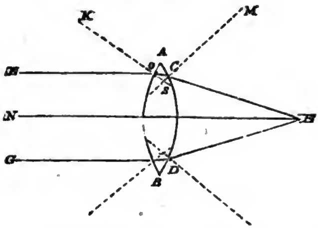
592. The course of the refracted rays, and, consequently, the position of the focus F, will vary according to the refractive power of the substance of which the lens is constructed. Thus, Sir David Brewster* has shown, that in a sphere of Tabasheer, whose refractive index is 1·11145, the focal distance for parallel rays will be four feet from the lens; in one of glass of a refractive index of 1·5, it will be but half an inch; and in one of zircon, whose refractive index is 2·0, it will coincide with the surface of the sphere. To find the focal distance of a sphere from its centre, divide the index of refraction of the material of which it is constructed, by twice its excess above unity, and the quotient will be the distance expressed in radii of the sphere. Thus, if the radius of a spherical lens be one inch, and its refractive index 1·6, we shall have 1·33 inches as the distance of the focus from the centre of the sphere; and by subtracting the radius, or one inch, we obtain the distance of F from the surface.

593. The course of a ray through a double convex lens, may be found in the same manner as that already explained in the case of a sphere (591). Let the lens AB be of the same material as the sphere, and ENG three rays entering it; N will pass on and emerge without refraction. The ray, E, will, on entering the lens, be refracted *towards* the perpendicular KOS; and on emerging from C into a rarer medium, it will be again refracted, but in a contrary direction, or *from* the line SCM, drawn perpendicular to the point of emergence. By a similar process, the course of the ray G may be ascertained; ENG will thus be found to meet at F, which is the principal focus of the lens. The amount of refraction experienced by the rays on entering and emerging from the lens, may be found precisely as in the case of refraction through a sphere (591). Taking the ray E as an example: on entering the lens it will be re-

* Treatise on Optics, p. 37. London, 1831.

fracted, so that the sine of the angle KOE will be to the sine of OCS nearly as 1·60 to 1; and on emerging from the lens at C, the sine of CSO will be to the sine of CMF as 0·6252 to 1.0 (580).

Fig. 293.



If the rays incident on the lens AB be *converging*, the focus will be nearer the surface of the lens than F; but if *diverging*, their focus will fall beyond that for parallel rays. The course of refracted rays, through plano-convex lenses, as well as through convex lenses of unequal curvature, may be found by the process already described for double convex glasses of equal curvature.

594. The focal length F (592) of convex lenses of all kinds, may be found by the following formulæ:

Radius of curvature of one surface $= r$.
. . . . of the other $= r'$.
Distance of the source of light $= d$.
Distance of the point of convergence of the rays from the lens $= d'$.
Thickness of the lens . . $= t$.

* For *Parallel rays.*

(A.) Double convex lenses of equal curvature . . . . $F = r$.

(B.) Double convex lenses of unequal curvature

$$F = \frac{2\,(r \times r')}{r + r'}.$$

(C.) Plano-convex lenses:

1, plane surface exposed to the rays . . $F = 2\,r$.

2, convex surface exposed to the rays . . $F = 2\,r \frac{2\,t}{3}$.

** *Diverging rays.*

(D.) Unequally double convex lenses $F = \dfrac{2\,(r \times r') \times d}{\{(r+r') \times d\} - 2(r \times r')}$

(E.) Equally double convex lenses . $F = \dfrac{d \times r}{d - r}$.

(F.) Plano-convex lenses . . . . $F = \dfrac{d \times r}{d - 2r}$.

*** *Converging rays.*

G.) Equally double convex lens . $F = \frac{d' \times r}{d' + r}.$

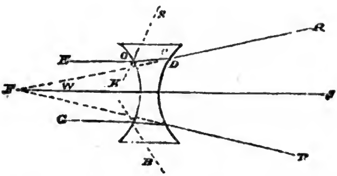
(H.) Double convex lenses of unequal curvature

$$F = \frac{2 (r \times r') \times d'}{\{ (r + r' \times d' \} + 2 (r \times r.)}$$

(I.) Plano-convex lenses . . . . $F = \frac{2 (d' \times r)}{d' - 2r.}$

595. To find the course of rays incident on a double concave lens, as AB, let ENG be as before, the rays of which, N, will pass through without refraction. E, on reaching O, will enter the glass, and become bent *towards* KS, a line perpendicular to the point of incidence, in such a manner, that the sine of the angle EOK will be to the sine of SOC, in the ratio of the index of refraction of

Fig. 294.



the glass to that of the air, as in the case of the convex lens (593). On reaching D, the ray EOC will emerge and undergo a second refraction, by which its divergence will be increased. The course of the ray G may be found in a similar manner. Thus, the parallel rays ENG are made to diverge by refraction through a concave lens, instead of converging, as in a convex glass. The emergent rays EST will diverge in the same manner as they would if they had proceeded from a radiant point at F, as shown by the dotted lines FT, FR; this point is the principal focus of the lens, and is a *virtual*, *apparent*, or *negative* focus, as in the case of reflection from convex mirrors (480).

The course of refracted rays through plano-concave and double-concave lenses, of unequal curvature, may be found by a similar process. From an inspection of the last diagram, it is clear, that if the incident rays on a concave refracting surface be converging, their negative focus will be nearer the lens; and if diverging, further from it than the principal focus F.

596. The negative focal lengths, for parallel rays of all the varieties of concave lenses, may be found by means of the formulæ already given for convex glasses. Their foci for converging rays may be found by the formulæ for diverging rays and convex lenses (594, DEF), and *vice versa.*

597. The action of menisci (590, H) and concavo-convex lenses on rays of light, is precisely the same as that of convex and concave lenses of the same focal length; the foci in the former being real or positive, whilst in the latter they are virtual and negative. In both varieties of lenses, the foci may be found in the following formulæ:

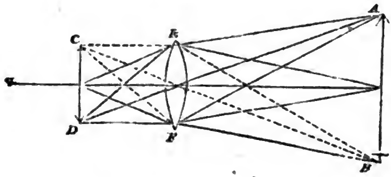
(A.) For parallel rays . . . . $F = \frac{2 (r \times r')}{r - r'}.$

(B.) For diverging or converging rays $F = \frac{(r \times r') \times 2\,d}{\{(r-r') \times d\} + 2(r \times r')}$.

598. Caustic curves are formed by the intersection of luminous rays during refraction, in the same manner as by refraction (576). They may be seen by holding a glass sphere near the candle, and allowing the refracted rays to fall, after passing through the sphere, on a sheet of paper held nearly parallel to the horizontal axis of the sphere; a luminous figure, bounded by two sharp curves, will be observed, meeting at the point corresponding to the focus of the lens. These curves may be more distinctly seen by covering a cylindrical glass vessel, as a common tumbler, with black paper to about an inch of the top; pour water into this vessel, until it rises half an inch above the level of the paper. Cut a piece of white card, so that when placed at the level of the black paper, and perpendicular to the axes of the vessel, it may half surround the glass; then hold the latter up to the sun, or before a candle, with the card away from the source of light. The luminous rays passing through the water will be refracted to a focus on the card; and a triangular luminous figure, bounded by caustic curves, will be depicted upon it.

599. Images are formed by lenses in the same manner as they are by mirrors (570). Let AB be an object situated at a considerable distance: the

Fig. 295.



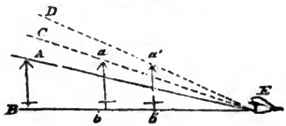
rays propagated from it will, on reaching the convex lens EF, suffer refraction, and after emergence will paint on a screen, placed near its principal focus (589), the image CD of the object, but in an inverted position in consequence of the crossing of the rays. If the screen be removed, and a piece of ground glass be placed at CD, the eye placed behind it, as at G, will see the image very distinctly; then let the glass be removed, and if the eye has been placed within the limits of distinct vision, a picture of the object will be seen painted in the air, a little beyond the principal focus of the lens.

600. If the object be within a moderate distance of the lens, its image will be formed on a screen as before; and will be visible most distinctly when the object and the screen are each placed in the conjugate foci (573) of the lens. If the object be still nearer, and it be viewed through one of the modifications of the convex lens, it will appear larger, and if through a concave lens, smaller than it really is. This curious property of lenses entirely depends upon the apparent angle under which the object is viewed. Taking first the case of the double convex lens, as AB (593), let the rays ENG be supposed to pass from an object placed near it, and the eye be placed between the lens and its focus F: under these circumstances, the object will appear to be larger than it really is; for if the rays FC, FD be produced, they will diverge at a very considerable angle, and, as bodies always appear to be placed in the direction pursued by the rays, which ultimately reach the eye (589), the rays FC, FD will appear to have passed from the object in right lines, and the object will

appear to the eye to be sufficiently large to fill up the whole opening of the angle. If, on the contrary, an object be viewed through a concave lens AB (595), it will appear to be diminished, because it is visible under a less apparent angle. For if an object be placed so that its rays ENG suffer refraction in the double concave lens, they will diverge, and the object will appear to be situated in the direction of the right lines RF, TF, included in the angle of convergence of those rays.

601. The manner in which the eye judges of the size of an object, according to the apparent angle under which it is visible, may be readily shown. If the eye placed at E views an object AB placed at such a distance that the right lines AE, BE, connecting it to the eye, may form an angle of 20°, it will appear of a certain magnitude. Approach AB to the position *ab*, it is evident that it will appear under a greater apparent angle than before, as a line C, passing through it to the eye, will, with B, describe a larger angle, and judging of its size from this angle, it will appear to be larger than when at AB. Bring *ab* to the position *a'b'*, it will then appear to be twice as large as it was when at AB; for D forms with B an angle of 40° and $40 \div 20 = 2$.

Fig. 296.



Thus, it is evident, that in viewing an object through a lens, the longer the focal distance the lesser apparent angle is it seen under, and *cæteris paribus*, the smaller it appears; whilst the shorter the focal length, the greater the apparent visual angle of the object, and the larger it appears. In the above account of the refraction of rays, and magnifying or diminishing power of lenses, it must be recollected, that the lenses under consideration are supposed to be denser, or of greater refractive power, than the medium in which they are immersed. For if they be rarer, or of less refractive power, then concave lenses will converge rays and magnify objects, whilst convex ones will diverge rays and diminish objects.

602. The magnifying power of a lens may be determined by the limit of distinct vision for minute objects, which is generally about five inches, divided by the focal length of the lens. This refers to its linear magnifying power, and only to the number of times it is magnified in length; its superficial power being obtained by squaring its linear, and represents the number of times its whole surface appears to be magnified.

Focal length of lenses in inches.	Magnifying power. Linear.	Superficial.
5	1·00	1
4	1·25	1·5625
3	1·66	2·7556
2	2·50	6·25
1	5·00	25·
$\frac{1}{10}$	50·00	250.

603. On referring to the diagram of the course of rays refracted by a convex lens (599), it will be seen that the rays passing nearest the axis of the lens will be refracted to a focus at a greater distance from the glass, than those which pass nearer the circumference. On holding a screen of ground

glass near the focus of the central rays, a picture of an object on the other side will be seen very vivid in its centre, but less distinctly defined at its edges; on gradually withdrawing the screen, the marginal portion of the picture will become more vivid as the centre loses its distinctness. Hence, it is obvious, that no object can be seen, with perfect distinctness, in every part through a convex lens, at the same moment, in consequence of this *spherical aberration*, as it is termed. In a plano-convex lens, with its convex side towards the object, this *aberration* amounts to 1·17 of the thickness of the lens; but when the flat side is towards the object, amounts to 4·5. In a double convex lens, with equal radii of curvature, the aberration is 1·67 of its thickness.

These rules apply equally to the varieties of concave lenses.

To remedy this aberration, elliptic and hyperbolic lenses have been proposed, but the difficulty of constructing them has hitherto proved an effectual bar to their general adoption. By means of the meniscus, spherical aberration may be nearly completely removed, if the convex surface be turned towards the object; providing the distance of the points of convergence or divergence from the centre of the first surface, be to its radius as the index of refraction of the lens is to unity. By combinations of lenses, the spherical aberration may be reduced to an insensible quantity; these are fully described in all works on practical optics.

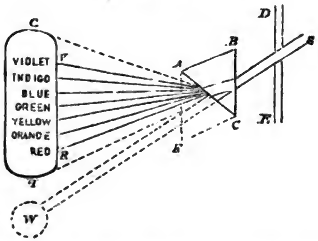
604. Spherical aberration is also observed in concave mirrors, and, as in lenses, interfere considerably with the distinctness of the image. This source of error in experiments in which mirrors are employed, can only be effectually prevented by giving to the reflecting surface such a figure, as will enable it to reflect all the rays incident upon it to one focus. The parabola and ellipse possess this property, and nothing but the mechanical difficulty of constructing mirrors of these figures prevents their being employed instead of spherical mirrors.

CHAPTER XXIII.

UNPOLARIZED LIGHT. (CHROMATIC PHENOMENA.)

605. If a number of luminous undulations be propagated through a prism, so that rays may leave it at the same angle with regard to the sides as they entered it, their physical characters become remarkably affected. The light not only appears to emerge as if it had been refracted or bent towards the thick part of the prism (589), but it becomes resolved into a set of undulations varying in amplitude and rapidity; and these are rendered obvious after leaving the prism, by their producing the phenomena of colors (560) when received on a white screen. Thus, through a hole in the shutter DE, let a ray of light SW, be transmitted; interpose a glass prism ABC, so that the ray may be refracted through it, and a long *spectrum* composed of bands of different

Fig. 297.



colors insensibly passing into each other will appear on a screen CH, placed at a proper distance. The upper colored part of this *spectrum* will be deep violet, and the lowest a dark red. This remarkable experiment was first performed by Newton,* and is usually termed the prismatic decomposition of

* Optice, lib. i., part 2, prop. 3, exp. 7.

light—white light being considered as being composed of seven distinct and *homogeneous* colors. But it is almost impossible to point out in the spectrum, as it is termed, any distinct line of demarkation between adjacent tints: for as the violet, indigo, and blue melt into each other, the latter color and green can scarcely be distinguished at their point of junction, and the yellow, orange, and red are still more closely united. So that, although Sir Isaac Newton adopted seven, as the number of primary colors, it is better with Euler to consider that, whilst the extreme violet is produced by the greater number of undulations, and the red by the smallest number, in a given time, there exists between these extremes every degree of variation in the rapidity of undulatory movement, and consequently infinite varieties of tints and colors.

606. Aided by a friend, whose perception of colors he considered to be very delicate, Sir Isaac measured with as much accuracy as possibly the limits of the different colored bands of the spectrum; he found their lengths, reckoning from the violet to the red, to be nearly in the ratio of the numbers $\frac{8}{9}$, $\frac{5}{6}$, $\frac{3}{4}$, $\frac{2}{3}$, $\frac{3}{5}$, $\frac{9}{16}$, $\frac{1}{2}$, a series nearly corresponding to the intervals of sound in the diatonic scale or gamut. The following are the linear measures of the spectrum made by Newton, (who unfortunately did not describe the kind of glass of which his prism was constructed), compared with similar measures made by Fraunhöfer with a prism of flint-glass,—each philosopher dividing the entire length of the spectrum into 360 parts:

	Red.	Orange.	Yellow.	Green.	Blue.	Indigo.	Violet.
Newton .	45	27	40	60	60	48	80
Fraunhöfer	56	27	27	46	48	47	109

607. As in the experiment above detailed (509), the violet rays undergo the greatest, and the red the smallest amount of deviation from the original direction of the ray SW; the former are termed the most, and the latter the least refrangible rays. When prisms of crown and flint-glass are used, the following are the indices of refraction (484) of the different colored rays:

	Red	Orange.	Yellow.	Green.	Blue.	Indigo.	Violet.
Crown-glass	1·5258	1·5268	1·5296	1·5330	1·5360	1·5417	1·5466
Flint-glass	1·6277	1·6297	1·6350	1·6420	1·6483	1·6603	1·6711

608. If a second prism AFC of precisely the same kind be applied to the first ABC, as shown in the figure (605), the colors will vanish from the screen; the undulations will be reduced to a uniform velocity; and white light will

be produced. This is termed *the recomposition of white light*; and as ABCF represents the section of a parallelogram, it is evident that resolution and recomposition of the luminous undulations ensue whenever they are propagated through a plate of glass, which may be considered as being made up of two very acute angled prisms applied to each other so that their apices and bases coincide.

The recombination of the colored rays may be also shown by holding a convex lens between the prism and the screen, which, if sufficiently near the former, will bring all the rays nearly to a focus, and reproduce white light.

609. From a set of accurate admeasurements made by Newton, the following table,* showing the lengths and rapidity of undulations producing the principal colored rays of the spectrum, has been constructed:

Colored Rays.	Length of luminous waves in parts of an inch.	Number of undulations in an inch.	Number of undulations in a second.
Extreme Red	0·0000266	37640	458 mils. of mils.
Red	0·0000256	39180	477 " "
Intermediate	0·0000246	40720	495 " "
Orange	0·0000240	41610	506 " "
Intermediate	0·0000235	42510	517 " "
Yellow	0·0000227	44000	535 " "
Intermediate	0·0000219	45600	555 " "
Green	0·0000211	47460	577 " "
Intermediate	0·0000203	49320	600 " "
Blue	0·0000196	51110	622 " "
Intermediate	0·0000189	52910	644 " "
Indigo	0·0000185	54070	658 " "
Intermediate	0·0000181	55240	672 " "
Violet	0·0000174	57490	699 " "
Extreme Violet	0·0000167	59750	727 " "

Thus red light is presumed to be caused by the ethereal medium performing in a given time about half as many oscillations or undulations as are necessary to generate violet light. Hence the waves of the latter are nearly of half the length of those of red light. It may be estimated that about 421 billions of waves are required to propagate red light during one second of time, and 799 billions to generate violet light during the same period.

610. From some beautiful researches of Sir John Herschel, in connection with the photographic powers of the spectrum (844), it appears certain that a band of colored light of still higher refrangibility than the violet may be detected just beyond the limits of that tint. This new band is barely luminous, and has been denominated the *lavender* band by its discoverer. From his more recent observations, Sir John, however, suggests the possibility of its possessing a barely luminous yellow color.

611. The seven colors of the solar spectrum are generally regarded as *simple*, because they cannot be separated into others by a second refraction through a prism, in which they differ from the tinted light obtained by passing the sun's beams through most varieties of colored glasses. When light passes through even the most transparent medium, as water or glass, some of

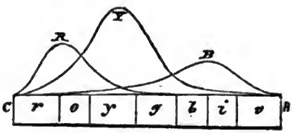
* Treatise on Light, in Encyclop. Metrop., by Sir John Herschel, 575.

its undulations become checked, and these vary in quantity according to the opacity of the substance; the transmitted undulations, whose rays ultimately reach the eye, communicate the sensation of that color, which is produced by the undulations of *white* light *minus* those which have been checked or absorbed whilst passing through the given medium. Thus, on holding a piece of small blue glass between the eye and the light, the transmitted rays will be of a fine blue color, and consist of a mixture of all those undulations which have not been checked by the glass; and if decomposed by the prism, will exhibit the usual *spectrum* (605), deficient only in those rays which were absorbed by the blue glass.

612. The rays thus absorbed by the blue glass are the red, with some of the blue. On examining the solar spectrum through such a piece of glass, which is best done by placing it before a prism, through which the observer is regarding a hole in the window-shutter, Sir David Brewster found that the greater part of the red and orange rays had disappeared. The yellow band appeared greatly increased in breadth, encroaching on the spaces formerly covered by the orange on one side, and the green on the other. Hence, the colored glass had absorbed those rays which, when mixed with the yellow, constitute orange and green, and consequently the green of the spectrum becomes decomposed into blue and yellow, and the orange into yellow and red. This has been by Sir David termed the simplification of the spectrum, by absorption, and greatly corroborates the views of those philosophers who have contended for the existence of but three *primary* colors, as red, yellow, and blue.

613. The solar spectrum may therefore be regarded as composed of three spectra of equal lengths overlapping each other, the red having its greatest intensity in the middle of the red space; the yellow in the middle of the band of that color, and the maximum of the blue between the band of that color and the indigo. Sir David has exhibited by means of three curves the intensities of tint of the three spectra, which he conceives to constitute the solar spectrum. Thus, if CH represent this spectrum, the red curve R commences abruptly, at C, and gradually declines to H; the yellow one, Y, commences less abruptly; and the blue one, B, begins with a very gradual curve—the heights of these curves, or lengths of their ordinates, represent the intensities of the tints of these *primary spectra* in every part of CH.

Fig. 298.



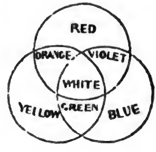
Placing R for the primary red, B for the primary blue, and Y for the primary yellow rays, the following will be a view of the proportions in which these rays exist in the spectrum, and in white light:

Color.	Proporiion of primary rays.
White	20 R + 30 Y + 50 B
Red	8 R
Orange	7 R + 7 Y
Yellow	8 Y
Green	13 Y + 10 B
Blue	6 Y + 12 B
Indigo	12 B
Violet	15 B + 5 R

614. Each of the prismatic colors has some other which is said to be complementary (642) to it, and which when combined with it produces white

light. If we regard the indigo as a separate color and regard it as a deeper shade of blue, the remaining six may be regarded as composed of three primary (611) and three secondary colors. The complementary colors to each of the former will be the compound tint made by blending the other two, whilst the complementary tint to each of the latter will be that primary color which does not enter into its composition. This may be seen at a glance by the following diagram consisting of three intersecting circles each representing a primary tint. In the centre, where they all overlap, white light is produced, at the other parts the complementary colors are exactly opposite each other.

Fig. 299.



615. Media of various colors absorb different primary rays, by checking the undulations producing them; thus, the piece of blue glass already referred to (612), checked or absorbed the red, and part of the blue; some pieces of red glass, or a combination of blue and red, absorb every ray except the homogeneous red. A solution of the ammoniacal-sulphate of copper transmits the violet, but checks all other undulations; while the ammoniacal-oxalate of nickel checks the violet, and transmits the blue and red. This remarkable absorptive power of different substances becomes curiously modified by heat, as shown by the tints assumed by various substances at different temperatures; thus, the periodide of mercury turns yellow, binoxide of mercury black, and the salts of cobalt blue, on being heated.

616. On examining the solar spectrum (605), the green rays are observed to be placed very nearly in the centre, and are hence frequently termed the *mean* or *medium rays* of the spectrum. If, instead of using the prism referred to (509), one of the same kind of glass, but of greater refracting angle, be employed, the length of the spectrum, or distance of the mean rays from the extremities, will be increased; and diminished, if the refracting angle of the prism be lessened. But when the spectra produced by two prisms, one of flint, and the other of crown-glass of equal angles, be examined, that produced by the latter will be found to be shorter than that by the former; hence flint-glass is said to have a greater *dispersing power* than crown-glass, because it spreads or disperses the spectrum over a greater extent of space than the other kind of glass. A thin hollow prism of glass filled with oil of cassia, produced a spectrum of twice the length of one produced by a prism of solid glass, on account of the great dispersive power of that fluid.

617. If the prism ABC be of flint-glass, and one of crown-glass AFC be applied to it, the spectrum will disappear, and the spot of light W will be reproduced, not colorless, as when the prisms were of the same kind of glass (608), but tinted on one side with purple, and on the other with green light. This arises from the unequal lengths of the spectra produced by the prisms of different kinds of glass, and consequent different dispersive power, which prevents their (so to speak) completely neutralizing each other's effects.

618. The dispersing power of a substance is not proportional to its index of refraction, and may be calculated by dividing the differences of the indices of refraction for the red and violet rays, by the excess above unity of the index of refraction of the mean rays. Thus, the dispersive power of crown-glass is 0·03902 for $1·5466 - 1·5258 = ·0208$ (511), and $\frac{·02080}{·5330} = 0·03902$.

The following table represents the dispersive power of a few substances, from the experiments of Sir D. Brewster:

Name.	Dispersive power.	Name.	Dispersive Power.
Oil of Cassia . .	0·139	Oil of Turpentine	0·042
Phosphorus . . .	0·128	Amber	0·041
Sulphuret Carbon	0·115	Diamond . . .	0·038
Oil of Cloves . .	0·062	Ether	0·037
Oil of Sassafras .	0·060	Castor Oil . . .	0·036
Rock Salt . . .	0·053	Water	00·35
Oil of Thyme . .	0.050	Plate-glass . . .	0·032
Oil of Caraway .	0·049	Sulphuric Acid .	0·031
Oil of Juniper . .	0.047	Alcohol	00·29
Flint-glass . . .	0·948	Rock Crystal . .	0.026

619. Not only are the total lengths of the spectra altered by the substitution of prisms of different dispersive powers, but the spaces occupied by the colored bands are not proportional to the altered length of the whole spectrum. This curious effect is termed the *irrationality* of the spectral dispersion, and is remarkably well shown by using two prisms, one of oil of cassia (616), the other of sulphuric acid. If the spectra produced be of the same length, the most refrangible colors, or those caused by the most rapid undulations (609), as the violet, indigo, and blue, will be found to occupy a much larger portion of the entire spectrum in the former than in the latter; the reverse being the case with the least refrangible rays, as red, orange, and yellow.

620. A very remarkable dispersive action is excited by a very small number of bodies on light, and to which attention has been lately directed by Sir John Herschel. This action seems chiefly confined to a variety of fluor spar, and to solutions of salts of two organic alkaloids, quina and æsculine. It is best observed in a solution of sulphate of quina in water acidulated with sulphuric acid. The fluid, although really colorless as water, disperses from its surface, even when in the thinnest films, a lively blue light, which when examined by viewing it through a prism, appears quite free from the pure red rays, part of the orange, and all the yellow: this has been termed *epipolic* dispersion (ἐπιπολὴ, a surface), from the seat of the action being at or near the surface of the liquid. The light thus *epipolised*, or, in other words, transmitted through the dispersing solution of quina, has undergone a physical change, and is no longer capable of developing the blue tint of sulphate of quina or other body possessing this property. This may be shown by filling a glass trough with water and placing behind it a tube filled with a solution of quina, taking care, by screens, to cut off all side light; the blue dispersed light will be beautifully distinct. Then replace the water in the trough by a solution of quina, and the blue tint previously visible in the tube will vanish.

621. If the solar rays, admitted through a narrow slit in a plate of metal,

be examined through a prism, a long spectrum traversed by numerous dark lines will become visible; and the late Dr. Ritchie found that if a bottle containing nitrous acid gas be interposed between the spectrum and the light, those lines will increase so much that the whole will present the appearance of a striped carpet.

These lines were first observed by Dr. Wollaston, and have since been carefully studied by Fraunhöfer, Brewster, and others. None of them exactly correspond to the boundaries of the colored bands, and they appear for the same kind of light to be perfectly constant. About a thousand of them have been counted by Sir D. Brewster. Several of these lines have been selected by Fraunhöfer, on account of their distinctness, and the facility with which they are discovered. These lines are known by the letters BCDEFGH: of these B lies in the red band nearest its extremity, C further advanced in the red, D is a strong double line in the orange space, very readily distinguished, E in the green, F in the blue, G in the indigo, and H in the violet spaces. There are, besides, three very remarkable lines in the green band between E and F.

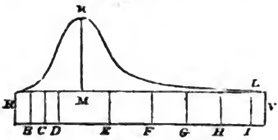
622. All these dark lines arise in all probability from certain undulations becoming checked or absorbed (612) during the passage of the light to our earth; those above referred to are constant only for the light derived directly or indirectly from the sun; for almost every fixed star has its own system of lines. The line D, indicating the place of a deficient ray, appears to be very constant in the light of the planets, and of many of the fixed stars. The spectrum from lamp-light appears deficient in three dark lines, D being replaced by a double bright one; the ray thus wanting in the solar spectrum, appears to correspond to the homogeneous light evolved during the combustion of alcohol, in which common salt has been dissolved, as in Brewster's monochromatic lamp.

623. The great value of these fixed lines, is their enabling us to take very accurate measures of the refractive (581) and dispersive power (605) of bodies. The following is an abstract from the table of Fraunhöfer's admeasurements of the refractive indices of water, oil of turpentine, flint, and crown-glass, for the rays B to H inclusive (621).

Refracting Medium.	Names of Rays referred to.						
	B	C	D	E	F	G	H
Water, 1st observation	1·330935	1·331712	1·333577	1·335851	1·337818	1·341293	1·344177
Water 2d observation	1·330977	1·331709	1·333577	1·335849	1·337788	1·341261	1·344162
Oil of Turpentine	1·470496	1·471530	1·474434	1·478353	1·481736	1·488198	1·493874
Crown-glass 1st specimen	1·524312	1·525299	1·527982	1·531372	1·534337	1·539908	1·554684
Flint-glass 1st spec'n	1·602042	1·603800	1·608494	1·614532	1·620042	1·630772	1·640373

624. The intensity of light in the solar spectrum appears to be greatest in the yellow band, and from that space it decreases to both extremities of the whole series of tints. Fraunhöfer has exhibited these variations in the light of the different parts of the spectrum by the curve RKL, the ordinates of which indicate the intensity of light in the different parts of the spectrum RV, in which

Fig. 300.



Fraunhöfer's lines (623) have been marked. Taking the ordinate KM falling nearly in the boundary between the yellow and orange as unity, the following will represent the illuminating power of the spectrum in the different portions occupied by Fraunhöfer's rays; the red extremity being indicated by R, and the violet by V:

Parts of the Spectrum.	R	B	C	D	E	F	G	H	V
Intensities of light in K; M = 1	0·0	0·032	0·94	0·64	0·48	0·17	0·031	0·056	0·

625. The calorific powers of the spectrum increase from the violet to the red extremity, and even extend beyond it, the obscure space bounding the red extremity possessing a higher temperature than the red band itself (H 605); so that it is evident, that when luminous undulations are propagated through a prism, a certain amount of them move with too little rapidity to communicate to the eye the sensation of light, and are only to be recognized by their calorific effects. These rays of non-luminous heat are less refrangible than the rays of red light, and are therefore found in the greatest abundance beyond the band of that color.

These calorifie rays have their situation altered according to the refracting medium of which the prism is constructed; being, according to Prof. Seebeck, in the greatest number in the yellow band, when a prism of water; in the orange, when one of sulphuric acid; in the middle of the red, when one of crown-glass; and beyond the red, when a prism of flint-glass is used. These phenomena are explicable on the supposition that there exist in the solar beams, rays of heat of different refrangibilities (851). Consequently the refractive power for heat of the medium of which the prism is composed will materially affect the dispersion of radiant heat over the luminous spectrum.

From the observations of Nobili and Melloni, on a spectrum produced by a rock-salt prism, the highest temperature was found beyond the red, and about as far distant from it on one side as the blue band was from it on the other. The following were the results obtained by Sir H. Englefield:

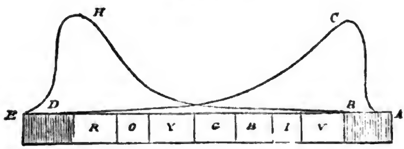
Color of band in the spectrum . .	Blue.	Green.	Yellow.	Red.	Beyond the Red.
Temp. by Fahrenheit's thermometer	56°	58°	62°	72°	79°

626. The chemical action of solar light, in producing chemical combination and decomposition, has been long known, and this, like the heating power,

appears to reside in greater intensity at one end of the spectrum than the other. This may be shown by dipping in a solution of nitrate of silver a slip of paper, previously washed over with a solution of common salt; on drying this, and exposing it to the action of the solar spectrum, a very remarkable effect will be observed. In the course of a few minutes the chloride of silver with which the paper was imbued, will become of a deep slate color in the violet, and in the sombre space beyond it; whilst in the yellow, orange and red, it will remain scarcely affected, its color being less altered in the blue than in the violet, and still less changed in the green (864). Thus the chemical action of the different rays of the spectrum appears to be concentrated in the violet band, and in the dark space beyond it, at the directly opposite end to the seat of the calorific rays, including the lavender band (610) noticed by Sir John Herschel. So that there is a reason to believe that those undulations which are propagated through a prism with too great rapidity to act on the organ of vision, possess the power of exerting certain chemical effects on many substances, in the same manner that calorific effects are exerted by those undulations which move with two little rapidity to produce the sensation of light.* Granting this, we met with another circumstance in which the propagation of light by the undulations of ether, and of sound by those of air, correspond. For it has been already shown that to most persons aërial waves moving with a velocity sufficient to strike the ear less than 16, or more than about 8,000 times in a second, are inaudible (203); whilst ethereal undulations, if less frequently repeated than 458 millions of millions, or more frequently than 727 millions of millions of times in a second, are incapable of acting on the visual organs.

627. If DB represent the solar spectrum produced by flint-glass, and AB DE the non-luminous portions beyond it, at each extremity, the curve EHB will give an idea of the position of the calorific rays, and ACD the position of the chemical rays. The longest ordinate of the curve EHB falls without the red ray R in the obscure space beyond it, where the calorific effects are most manifest;

Fig. 301.



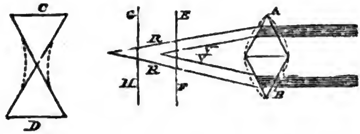
and the longest ordinate of the chemical curve ACD falls in the dark space beyond the violet ray V, where the action on chloride of silver appears to be most intense. Both curves rise abruptly, and gradually decline to zero at opposite ends of the spectrum.

628. When light passes through a prism, it becomes resolved into a series of colored rays, of which the most refrangible become bent towards the thick part of the refractor (605); but when it passes through lenses, an analogous resolution into colored rays is not so readily observed, although it does exist, and to so great a degree as to interfere most seriously with the perfection of microscopes and telescopes, causing the image to be tinted at its edges with various colors, producing *chromatic aberration.* The section of a convex lens may be represented by two prisms AB, placed base to base, and that of a concave by

* Vide Chapter XXX.

two others CD, with their apices in contact. On a ray of light being incident upon such elementary prisms, it undergoes refraction and resolution into co-

Fig. 302.



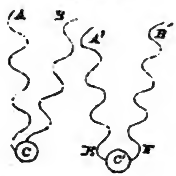
lored rays, and the most frangible, or violet VV, are brought to a focus nearer the lens, and the least refrangible, or red RR, to one at a greater distance; so that, on placing a piece of paper at EF, the image of the sun or other luminous body will be seen surrounded by a violet or a purple border, which will be replaced by a red one on moving the paper to GH.

629. The greatest improvement ever made in optical instruments consists in the discovery of achromatic lenses; these are formed by combining a concave and a convex lens, constructed of substances of different dispersive powers (616). Thus, if a convex lens made of crown-glass, whose dispersive power is 0·036, be combined with a concave lens of flint glass whose power of dispersion is 0·0393, a compound lens will be constructed capable of refracting white light to a colorless focus. This combination would be perfect, if the colored bands produced by prisms of these two glasses were of equal breadth; but in consequence of the irrationality of the spectra (619), this perfect neutralization of tint takes place only with the extreme rays, the violet and red; the intermediate ones imperfectly destroying each other, cause the object viewed through such compound lenses to be bordered by fringes, which, however, are so faint, that for all ordinary purposes the combination may be considered as achromatic. By employing certain fluids, as hydrochloride acid confined between two lenses of crown-glass, Dr. Blair overcame this remaining difficulty, and obtained a compound lens, perfectly achromatic for the intermediate as for the extreme rays.

Fig. 303.

630. When two or more undulations emanating from the same source, act on a particle of ether, it oscillates with an intensity corresponding to the combined force of the undulations (554); the same thing occurs, providing the latter are of equal length, or differ by a given number of entire undulations, even when they emanate from different sources. But if the waves acting on a particle of ether differ by any fractional number of undulations, they interfere and oppose each other's action, and thus actually produce partial or total darkness. To render this more clear, if any number of rays produced by 1, 2, 3, or any whole number of undulations, act in concert, increase of effect is produced; but when a certain portion of the rays are produced by 1, 2, 3, or any whole number, whilst another set are produced by $1\frac{1}{2}$, $2\frac{1}{2}$, $3\frac{1}{2}$, or any fractional number of undulations, interference, and obscuration take place, from the mutual checking of a certain number of waves. This may be rendered more intelligible by drawing two sets of waves containing the same number of undulations, as AB;

Fig. 304.



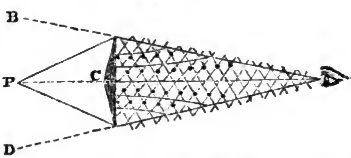
any particle of ether at c must be made to assume a movement corresponding to the combined action of A and B, and a correspondiug intensity of light will result. Then alter the relative position of AB, so that A may begin one-half an undulation later than B, as at A′B′, then it is at once seen that they will be always in opposite phases; for any particle of ether at c′ will be acted on in opposite directions by A′ B′; for whilst the undulation F is moving from right to left, E is moving in an opposite direction, and mutually opposing, they will cease to act on a particle of ether at c, producing darkness by the conflict of two luminous undulations. If the waves of light, instead of meeting at the end of an entire half-undulation, encounter at any fractional part of one, partial interference will ensue, and colors will be developed, bearing a relation to the length and velocity of the undulation remaining undestroyed.

In this explanation of the interference of luminous waves of ether, it must be borne in mind that the series of progressive undulations here figured are assumed merely for the sake of facility of demonstration, as it has been already pointed out (552) that undulations of highly elastic media, as ether, consist of a series of alternate expansions and contractions of spherical molecules in opposite directions, and not of any truly progressive movements.

631. We have already seen that the interference of sonorous undulations produce silence; and in the extension of this fact to luminous waves, we meet with a striking analogy between the oscillations of particles of ether and of air, the difference being rather in degree than in kind (176, 230). The combined or diminished action of luminous undulations, bears a remarkable relation to musical discords and concords, the former being produced when sonorous vibrations, differing in their rapidity by fractional portions, interfere; and the latter when similar vibrations, bearing to each other a relation in whole numbers, strike the ear together.

632. An experimental demonstration of the interference of luminous undulations may be obtained, by an experiment first proposed by M. Fresnel. Allow a ray of light to fall in the direction PC upon a prism with an exceedingly obtuse angle. Then the eye placed at A will see the radiant point double, apparently in the directions BD, and between these two points, a series of dark and bright lines perpendicular to a line joining the two images. If homogeneous light (605) be employed, as that from a spirit lamp with a salted wick, the lines will be alternately yellow and black; but if common light be employed, they will be tinted with the prismatic colors.

Fig. 305.

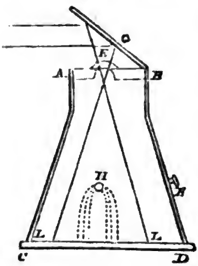


The explanation of these colors is plain enough. The two images BD may be regarded as the centres of two series of undulations, put, as we have seen, in the case of two series of waves in water (176). When these undulations meet in the same phase light is developed, and when in opposite phases, interference is produced, and darkness or colored light occurs, according to cir-

cumstances. In the above figure, the dotted curves show the boundaries of the half, and the entire curves those of the entire undulations. The series of dots show the points where luminous interference occurs. A fine *experimentum crucis*, proving the real origin of these dark bands, is made by covering up one-half of the prism; the interfering rays are then cut off and the bands instantly vanish.

633. An interesting set of illustrations of the doctrine of luminous interference, is met with in the phenomena of diffraction discovered by Grimaldi, a Jesuit of Bologna. To observe these properly, a beam of diverging light is necessary; this may be obtained by making a small hole in a window shutter, and receiving the light on a screen at the distance of some feet. If a convex lens, of small focal length, be fitted in the hole in the shutter, the light is refracted almost to a point, from whence it diverges in a manner extremely fitted for experiments on diffraction. For small experiments, a pyramidal box, ABCD, about two feet long, and blackened inside, may be advantageously employed; at E, a convex lens, of an inch focus, is fixed, on which, by means of the plane mirror G, a sunbeam can be readily thrown. The light is refracted by the lens to a point, and then diverging, is received on a sheet of white paper placed at the bottom of the box; by means of a door shown at F in the section, the bottom becomes easily visible, without admitting any quantity of extraneous light.

Fig. 306.



634. If any small opaque bodies, as hairs, pins, &c., be held in the beam of diverging light, ELL, their shadows will be thrown on the bottom of the box, surrounded by colored fringes. If H be a section of a pin thus exposed, the fringes are seen surrounding its shadow, as though they were produced by colored rays passing by its margin, not in straight lines, but in hyperbolic curves, as shown by intercepting them at different distances by a piece of card: when their decrease in extent will be found to be much more gradual than if the light passed by H in right lines. Besides these external fringes, there are internal ones within the shadow, which, if the body be narrow, as a pin, becomes completely filled with them. These colors are, as Lord Brougham* has long ago shown, in harmonic proportion, like those of the solar spectrum (606). The tints of the colored fringes, reckoning from the shadow, succeed each other in the following manner:

1st fringe—violet, indigo, blue, green, yellow, red.
2d fringe—blue, yellow, red.
3d fringe—pale blue, pale yellow, red.

If *homogeneous* light (605) be employed the fringes will be of the same color as this light, and their intervals will appear black. The fringes are broadest in red, narrowest in violet, and of intermediate breadth in the other colors of the spectrum.

635. These phenomena admit of ready explanation on the theory of interference (630), for the diverging light which passes by one side of the pin (634), meeting with that passing on the opposite side, coincide, and produce a line of white light, which ought to occupy the middle of the shadow. Whilst those rays which differ in their paths, as those produced by undulations, which pass obliquely past the pin *into* its shadow meeting with those which pass more directly on the opposite side, being of course unequal in

* Phil. Transactions, 1796.

their paths, encounter under different phases (534), and interfere (630), either checking the undulation entirely, and producing darkness, as when homogeneous light is used, or so partially checking it as to allow such a number of movements to be executed in a given time as shall be sufficient to produce a colored fringe.

636. In shadows of this kind, formed by narrow bodies, the middle is always occupied by a luminous line, as though the light had passed directly through the centre of the diffracting body. This very curious fact is best observed by holding a small disc of metal on a slip of glass, in the diverging light (633); the rays passing by its circumference are inflected, and meet, after traversing equal paths, in similar phases in the centre of the shadow, producing a brilliant spot of light. The shadow thus precisely resembles that of a circular disc perforated in the centre. This beautiful experiment is best performed by means of a drop of thick black ink, or a mixture of lamp-black and size, placed on a plate of glass, so as to form a circular spot about the tenth of an inch in diameter. For this modification of the original experiment of Fresnel, we are indebted to Professor Powell.

637. If a disc, perforated with a very small hole in the centre, be held in the beam of diverging light (630), the converse of the last experiment will be observed; for those undulations which pass directly through the aperture, interfere with those passing more obliquely, and produce a dark spot on that part of the shadow corresponding to the hole in the disc. Thus, we find light virtually changed to darkness, and darkness to light, by the *discord* or *concord*, of the luminous waves.

638. If two knife edges be held very near each other in the beam of light (633), beautifully colored fringes will be observed to border their shadow, and a dark line will, if they be sufficiently near, be seen to occupy the middle of the space, at which they are really separate. This result of luminous interference may be readily shown by fixing a slip of tin-foil on a plate of glass, and dividing it longitudinally; and very slighly separate the divided portions at one end, so that they may form a very acute angle with each other, as at ABCD. Hold this in the diverging light of the apparatus before described (633), about six inches from the bottom, so that it may form a well-defined shadow. The centre of the shadow, corresponding to the slit in the tin-foil, will be marked by an obscure line, and the shadow from this line will be covered with a beautiful set of fringes diverging from each other as they approach the apex of the acute angle F, formed by the coil, bounded on each side by hyperbolic curves, with their convex surfaces towards each other, as if diverging from vertices situated at EE. So that the widest parts of the curved fringes correspond to the apex of the angle formed by the slips of tin-foil. In the figure, FGG represent the projection of the slit in the foil on the paper on which the shadow falls. This experiment is an easy, although rough mode of repeating Newton's observations with the knife-blades.*

Fig. 307.

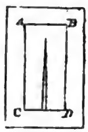
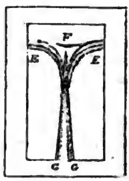


Fig. 308.



639. The explanation of the cause of colors by diffraction (633) is finely illustrated by placing a card on one side, and on a plane above or below the body H (633), so as to intercept some of the incident or diffracted light; the fringes then disappear, because one set of the undulations producing inter-

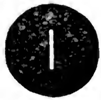
* Optice. Lib. iii. pars. i., obs. 10.

ference have been cut off. If a transparent body be substituted for the card, the fringes undergo a remarkable change, from the *retardation* of those undulations which are propagated through the transparent screen.

640. The beautiful phenomena of diffraction may be easily observed by viewing, in a darkened room, through a piece of the finest copper wire gauze, a series of objects, fixed in a large screen of black pasteboard, so placed as to prevent any light reaching the eye, except such as passes through the object. The following give particularly interesting results.

Fig. 309.

Fig. 310.



A. Fix six sewing needles over a hole cut in a piece of blackened wood, taking care their mutual distance corresponds to the thickness of a needle. On viewing this object at a proper distance through the gauze, each needle will appear transparent, the centre of each being occupied by a line of reddish light.

B. Examine in a similar manner a piece of tin-foil, in which a fine slit, about one-twentieth of an inch wide, has been carefully cut. The slit will seem widened from light entering the shadow, its centre being occupied by two vertical lines of bluish-black, whilst a series of colored bands will extend to a distance of half an inch on each side of the slit.

Fig. 311.

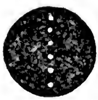
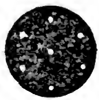


Fig. 312.



C. Make a line of small holes in a piece of tin-foil by means of a fine needle. Each hole will appear bordered with a reddish margin, whilst a series of spectral colored openings will appear in the foil for half an inch on each side of the real aperture.

D. Perforate a piece of tin-foil into a very fine needle, as shown in the figure. Each opening will, when examined as above, present nine colored squares like a window, and the spectra will be so numerous, that the foil will appear full of holes, admitting light of different colors.

641. The brilliant tints of soap-bubbles, and thin plates of different transparent bodies, afford other examples of interference of light; for the undulations reflected from their first surfaces interfere with those reflected from the second (567): and upon the amount of retardation thus experienced by the luminous waves, the varieties of colors observed in these thin plates depend. The colors of soap-bubbles are best seen by boiling a small quantity of soap with distilled water in a bottle, and corking it whilst boiling hot. The whole being secured from air, is allowed to cool, and on adroitly shaking the bottle, a large bubble, presenting the colored bands with great beauty, may be readily formed; this bubble is permanent for several hours, and affords every facility for examining its tints.

642. The colors of thin plates of air may be observed by pressing a convex lens on a plate of glass, and holding it in the light, so that rays reflected from it will pass to the eye. At the point of apparent contact with the lens and glass, a black spot will, under these circumstances, be visible; this is surrounded by a great number of rings of different colors, each series of tints consisting of fewer colors as they recede from the centre. On holding the glasses between the eye and the light, a set of rings will be observed, differing in color from those seen by reflection; and, *complementary* (614) to them, each ring possessing that color, which by mixing with the tint of the corresponding reflected ring, would produce white light. The following are the colors of the rings, observed by reflection and transmission, commencing from the centre or point of apparent contact, as given by Sir Isaac Newton.* The curved line, CA, represents the section of one-half the convex lens, and the straight one CB that of half the plane glass against which it is pressed.

Transmitted Rings.	*Reflected Rings.*
C	
White - -	Black,
Yellowish Red	Blue,
Black - -	White,
Violet - -	Yellow,
Blue - -	Red,
White - -	Violet,
Yellow - -	Blue,
Red - -	Green,
Violet - -	Yellow,
Blue - -	Red,
Green - -	Purple,
Yellow - -	Blue,
Red - -	Green,
	Yellow,
Greenish Blue -	Red,
Red - -	Green,
Bluish Green -	Red,
Red - -	Greenish Blue,
	Red.
B	A

643. The following are the thicknesses, expressed in millionth parts of inches, of plates of air, water, and glass, required to produce the different colored rings:

* Optice. Lib. ii., pars. 2.

Series or orders of colors.	Colors seen by Reflection.	Thickness of Plates producing them.		
		Air.	Water.	Glass.
First	Very black	0.50	0·38	0·33
	Black	1·00	0·75	0.66
	Blackish	2·00	1·50	1·30
	Pale sky-blue	2·40	1·80	1·55
	White (like polished silver	5·25	3·88	3·40
	Straw color	7·11	5· 3	4·60
	Orange-red (dried orange-peel)	8·00	6·00	5·17
	Red (geranium sanguineum)	9·00	6·75	5·80
Second	Violet (vapor of iodine)	11·17	8·38	7·20
	Indigo	12·83	9 62	8·18
	Blue	14·00	10·50	9·00
	Green (that of the sea)	15·12	11·33	9·70
	Lemon-yellow	16 29	12·20	10 40
	Orange (fresh rind of oranges)	17·22	13·00	11·11
	Bright red	18·33	13·75	11·84
	Dusky red	19·67	14·75	12·66
Third	Purple (flower of flax)	21·00	15·75	13·05
	Indigo	22·10	16·57	14·25
	Prussian blue	33·40	17·55	15·10
	Grass-green	25·20	18·90	16·25
	Pale yellow	27·14	20·33	17·50
	Rose-red	29·00	21·75	18·70
	Bluish-red	32·00	24·00	20·66
Fourth	Bluish-green	34·00	25·50	22·00
	Emerald-green	35·29	26·50	22·80
	Yellowish-green	36·00	27·00	23·22
	Pale rose-red	40·33	30·25	26·00
Fifth	Sea-green	46·00	34·10	29·66
	Pale rose-red	52·50	39·38	34·00
Sixth	Greenish-blue	58·75	44·00	38·00
	Pale rose-red	65·00	48·75	42·00
Seventh	Greenish-blue	71·00	53·25	·80
	Pale reddish-white	77·00	57·57	49·66

By aid of this table, the thickness of thin films of air, water or glass, may be readily determined by observing the colors they reflect. The comparative thickness of plates of two substances, reflecting the same color, are in the inverse ratio of their indices of refraction (579).

These rings may be exhibited by merely placing two plates of window-glass, about four inches square, together, and pressing them in the centre by means of a pointed piece of metal. The different colored rings, somewhat

eccentrically arranged, will appear with great beauty around the point where the pressure is applied.

644. When these rings are observed by homogeneous light (579), they present the same hue as that of the light itself; alternating with dark and almost non-luminous rings, and appear to possess the greatest breadth in red, and the least in violet light. These rings appear to be larger, in proportion as we look at them in a more oblique direction; this is best seen by examining the rings produced, when a glass prism is pressed on the surface of a convex lens.

The colored rings thus exhibited by thin plates, are produced by the interference of the light reflected by the first surface with that reflected from the second (567); for when either of these reflected rays is intercepted, the colors entirely vanish.

645. The rings seen by transmission, are produced by those undulations which are not reflected, and are consequently propagated through the thickness of both glasses. Those luminous rays, which, when combined with the reflected rays, produced white light, being propagated through the glass, produce the transmitted or complementary (538) rings.

From Newton's table (643), we see that air, at or below a thickness of half a millionth of an inch, and water and glass at a thickness of about one-third of a millionth of an inch, cease to reflect light, and appear, consequently, black. Films and fibres of quartz, so minute as not to be capable of propagating luminous undulations, have been met with and described by Sir David Brewster.

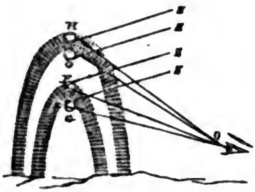
646. It is by no means necessary that very thin plates should be used to exhibit colors, for plates of any thickness, so arranged as to cause the interference of luminous undulations, will produce the same effect. This may be shown by fixing two slips of plate glass, about 0·10 inch distant from each other, by means of two pieces of wax, and then by pressing one end of each plate together, they may be so fixed as to describe a very acute angle with each other. On looking at a candle, through that part of the plates nearest each other, numerous reflected images of it will become visible; the first of them appears crossed by a series of beautiful bands or fringes. These increase in breadth by diminishing the inclination of the plates; they are produced by the interference of the waves of light reflected from both surfaces of each glass plate.

647. The colored rings, observed by regarding the sun, or other luminous body, through a piece of glass, covered with minute particles, as of dust, lycopodium, &c., or of water, by breathing on it, are all owing to the interference of luminous undulations inflected round the particles (634). A similar explanation will apply to the colors seen, by scattering fine powders or dust on, or before a mirror exposed to the solar rays. The beautiful tints presented by mother-of pearl, or other natural or artificial substances, whose surfaces are marked by minute striæ, are all explicable on the hypothesis of interference; all that is requisite to produce these colors being, that the depression shall be of such a depth as to cause an alteration in the path of rays incident upon them, equal to a fraction of the length of an undulation (554).

648. Among the natural phenomena which serve to illustrate the laws and principles laid down in this and the preceding chapters, the well-known rainbow and less frequent mirage especially deserve attention. The former consists of a colored arch, apparently suspended in the sky, and opposite to the sun, and is usually composed of two bows, termed primary and secondary, and sometimes even of other supplementary arches. The rainbow is never seen unless a shower of rain is falling, or the spray of water, as from a cataract, rising between the spectator and that portion of the sky opposite to the

sun. To explain the cause of these bows, let FE be two drops of water, and SS solar rays incident upon each of them, those which enter near their centre will be refracted to a focus, as in a sphere of glass (591). But those which enter near their upper part suffer refraction, during which the light becomes resolved into waves of different lengths, as in prismatic refraction (605), and colors are consequently produced; the violet ray being most, and the red least refracted, the other rays being arranged between them in the usual manner. As these refracted rays are incident at the back of the drop, within the limiting angle (580), they undergo total reflection and emerge at the lower parts, as G in the drop E, and present to the eye of the spectator a bow of the prismatic colors, bounded above by the red, and below by the violet rays.

Fig. 313.



When the solar rays enter the drops of rain from below, as at GH, they are refracted to the back of the drop, and undergo the same resolution into colored rays; thence are reflected to the top, and thence to the front of the drop, where they emerge, presenting to the spectator the appearance of a second bow, exterior to the first, and with its tints much fainter and reversed, in consequence of the rays having suffered two reflections in GH, whilst in DE they underwent but one.

CHAPTER XXIV.

POLARIZED LIGHT.

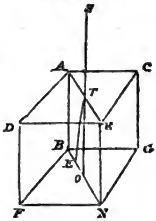
Ordinary and extraordinary rays of double refraction, 650. *Principal sections of crystals*, 651. *Double refractive power of various bodies*, 652. *Positive and negative, real and resultant axes of double refraction*, 653. *List of positive and negative crystals*, 654. *Huygenian law of rapidity of the two rays*, 655. *Intensity of refractive power in different parts of crystals*, 656. *Crystals with two axes*, 657. *Action of crystals on colored light*, 658. *Doubly refractive power acquired by change of structure*, 660. *Polarized light*, 661. *Planes of polarization*, 662. *Different modes of polarizing light*, 663—*by refraction through Iceland spar*, 664.—*Nichol's prism*, 665—*by absorption*, 666—*by reflection*, 669. *General properties of polarized light*, 670. *Polarization by refraction through glass-plates*, 675. *Partial polarization*, 676. *Ratio between polarizing angles and refractive index*, 678. *Polarization by internal refraction*, 680. *Polarization of homogeneous light*, 681. *Polarization by a bundle of transparent plates*, 682. *Polarized light in common daylight*, 683.

649. So far as we have yet examined the properties of light, we have learnt that when a ray is incident upon the surface of any refracting substance in a perpendicular direction, it undergoes no change in its course; but when incident obliquely, it becomes refracted according to a law already detailed (579). We have now to notice some very remarkable properties of a class

of refracting media, capable of dividing an incident beam into two portions differing from each other in their physical properties.

650. Let ABCDFGN be a rhomboid of Iceland spar (carbonate of lime), and a ray of light ST be incident upon one of its surfaces, in a perpendicular direction; instead of passing through without refraction as it would through glass, it will be divided into two rays, one TO being in the direction of the original ray, ST, and consequently unrefracted, and another, TE, which is bent or refracted. The former is called the *ordinary*, and the latter the *extraordinary* ray. If the ray ST, instead of being incident in a direction perpendicular to one of the faces, were oblique, it would on entering the crystal, be refracted into two rays, one of them the ordinary ray, obeying the general law of refraction (579), and the other, the extraordinary ray, following a different law, becoming refracted from an imaginary line connecting two opposite obtuse angles AN.

Fig. 314.



651. The double refraction of the incident ray may be readily observed by viewing through a rhomb of Iceland spar a card pierced with a small circular hole: on looking through the thickness of the crystal at the card, two holes will be visible, from the light entering the aperture in the card dividing into two rays whilst traversing the rhomb, before it reaches the eye. On turning the crystal round, whilst the object remains fixed, one of the spots of light will appear to revolve round the other. The fixed spot corresponding to the path of the ordinary ray.

A rhomb of Iceland spar, placed upon any object, as a line drawn on paper, will cause it to appear double, in consequence of this property of double refraction.

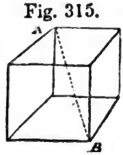
If the rhomb be gently turned round whilst on the line, one of the two lines at first visible will gradually disappear, and when the line on the paper lies in the same vertical plane as the imaginary one connects the obtuse angle of the crystal, they will merge into each other and appear single. No double refraction occurring along this line or in any direction parallel to it.

In the rhomb of spar, the plane, AEBN, passing through the crystal, and dividing it into two triangular prisms, is termed the *principal section* of the rhomb.

652. The property of resolving undulations propagated through them into two series differing in velocity, and consequently producing double refraction, is not confined to the varieties of carbonate of lime, but belongs in general to all crystals whose primitive form is neither a cube nor an octahedron. A vast number of crystals, as well as uncrystalized diaphanous substances, if not already possessing the doubly refracting structure, will assume it by exposure to heat, cold, compression, induration, and various other causes affecting their molecular arrangement (659). Some substances, as the tourmaline, are capable of double refracting light, when very thin, and act in the ordinary manner upon incident rays, when they are thick.

653. In all doubly refracting bodies, there are one or more directions, along which objects, when viewed through them, appear single (651); these are termed the *lines, or axes of double refraction.* In the case of Iceland spar, there is but a single axis of double refraction, in the direction of a line connecting its two obtuse trihedral angles, as shown by AB in the marginal figure. The axis of double refraction is not a fixed line, but merely indicates the direction of a plane, in which double refraction is absent; for if a rhomb of Iceland spar be split into any number of smaller ones, each will

Fig. 315.



possess its own axis of refraction. In uni-axial crystals, the axis corresponds to the geometrical axis, or a line around which the constituent molecules are symmetrically arranged. It occasionally happens that no double refraction exists in the axis of a crystal, in consequence of the presence of two doubly refractive forces neutralizing each other, as in mica; this is then termed the *resulting axis*, in contra-distinction to a real axis of double refraction. The course of the extraordinarily (650) refracted ray is constant for each crystal, with regard to the axis of double refraction, being refracted either towards it in *positive* crystals, as in quartz, or from it, in *negative* crystals, as in Iceland spar. Those crystals in which this ray is bent towards the axis, are said to have a positive, and when bent from it, a negative, axis of double refraction.

654. Crystals with one axis of double refraction (653), corresponding with the geometric axis of the crystal, include, according to Sir David Brewster, all those bodies which crystalize in rhomboids, regular hexaëdral prisms, and octaëdrons, or right prisms with square bases. The following are some of the crystals possessing a single axis of double refraction:

A. Positive Axis.	B. Negative Axis.
Dioptase.	Iceland spar.
Quartz.	Tourmaline.
Zircon.	Sapphire.
Titanite.	Emerald.
Apophyllite.	Ferrocyanide of potassium (some specimens).
Ice.	Ammoniaco-phosphate of magnesia.
Potass-sulphate of iron.	Mica (some specimens).
Boracite.	Cyanuret of mercury.

655. We have seen (651) that when a rhomb of calcareous spar is placed upon a line drawn on paper, the greatest separation of the two rays, and consequently of the images, occurs, when the line is parallel to the great diagonal of the crystal; and, on turning the latter round, the images gradually approach, and ultimately merge into each other when the line on the paper is parallel to the shortest diagonal. This arises in consequence of the extraordinary and ordinary rays being then placed in the principal section (651) of the crystal. With regard to the comparative rapidity of propagation of the two sets of undulations into which light incident on a doubly refracting crystal is resolved, Huygens has demonstrated that the difference between the squares of the rapidity is equal to unity divided by the square of the sine of angle formed by the ray with the axis. In calcareous spar the ordinary ray therefore moves with a greater velocity than the extraordinary one.

656. If uni-axial doubly refracting crystals (654) be supposed to be shaped into spheres, of which the line connecting the poles corresponds to the axis of double refraction in the original crystal, in positive refracting crystals as quartz, the index of extraordinary refraction will be found to increase from the pole to the equator of the sphere; whilst in negative refracting crystals, as calcareous spar, the index decreases from the poles or termination of the axis, to the equator at right angles to them.

In a sphere of calcareous spar the index of refraction of both rays will be the same, or, 1·654, if light be transmitted along the axis; at 45° from the latter, the index for the extraordinary ray will be 1·582, and at 90°, viz. at the equator, the index decreases to 1·482, from which point it increases to the opposite pole. In a sphere of quartz, the index of refraction for both rays

will at their axis be 1·5484, and at the equator the index of the ordinary ray remaining the same, that of the extraordinary one increases to 1·5582.

657. A large number of crystals, including those whose primitive forms are right, or oblique prisms with rectangular, rhombic, or oblique quadrangular bases, as well as octaëdrons with rectangular or rhombic bases, possess two axes of double refraction. These are to be regarded rather as resultant (653) than actual axes, as they merely point out the direction in which two doubly refracting forces present in the crystal neutralize each other. These axes do not correspond to any prominent lines in the crystal, and form various angles with each other; from the most acute, to one of 80·30, as in carbonate of potass, and to a right angle, as in sulphate of iron. The following list contains the names of some of the most important double-refracting crystals, with the measures formed by the inclination at their axis on each other, taken from a large table by Sir David Brewster:

A. Principal Axis of double Refraction. Positive.		B. Principal Axis. Negative.	
Names.	Angles formed by Resultant (653) Axes.	Names.	Angles formed by Resultant Axes.
Sulphate of nickel .	3° to 42°.1′	Nitrate of potassa .	5° 20′
Biborate of soda . .	28 42′	Carb. strontia . . .	6 56
Sulphate of baria . .	37 42	Talc	7 24
Spermaceti	37 40	Carb. lead	10 35
Heulandite	41 40	Mica, certain specimens	14 0
Soda-sulphate of magn.	46 49	Sulph. magnesia . .	37 24
Brazilian topaz . .	49 to 50	Carb. ammonia . .	43 24
Sulphate of strontia .	50	Sulphate of zinc . .	44 28
Sulphate of lime . .	60	Sugar	50
Nitrate of silver . .	62 16	Phosphate	55 20
Scottish topaz . . .	65 0	Tartrate potass . .	71 20
Sulphate of potass .	67 0	Tartaric acid . . .	79
Potass tartrate of soda	80 0		

658. In crystals with two axes of double refraction, the ray, equivalent to the ordinary ray (650), differs from that properly so called, as it does not obey the law of sines (579); so that the two sets of undulations, into which common light is resolved by a biaxial crystal, are both to be considered as producing extraordinary rays. This observation we owe to M. Fresnel. Crystals are occasionally met with possessing two axes of double refraction, for light of one color, and but one axis for light of another tint; thus Sir David Brewster found that glauberite possessed two axes mutually inclined at an angle of 5° for red light, and but one axis for violet light. Sir John Herschel found that the axes occasionally vary in inclination, according to the kind of light; thus, in the potassio-tartrate of soda, the inclination of the axis for violet light is 56°, and for red light 76°. In nitrate of potass, the inclination of the axes for violet light is greater than for red.

659. When glass is unequally heated, or suddenly cooled, it assumes a doubly refracting structure, the axes being variously situated, according to the shape of the substance (703). A solid cylinder of glass, heated by being plunged into hot oil, acquires a doubly refractive power, having one positive

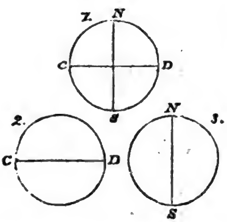
axis in the position of its geometric axis; and if previously heated and plunged into cold oil, it acquires a similar property, but its axis becomes negative (653). In both these cases the refracting power is transient, and vanishes as soon as all the parts of the cylinder have acquired the same temperature. A sphere of glass, similarly treated, becomes doubly refractive, but with innumerable axes, as is naturally the case in analcime, in which the axes are almost infinite. The crystaline lenses of all animals possess one or two axes of double refraction.

660. In the preceding chapters, we have regarded colorless light as the same after, as before, refraction or reflection; and the only modifications of it which we have examined, are its resolution into several series of undulations varying in length and velocity, as in prismatic refraction and diffraction or inflection (635); and its resolution into two series only, producing colored rays complementary to each other (614), as when white light is resolved into green and red, or yellow and violet. We have now to examine the changes undergone by a ray of light after it has been resolved into two series of colorless beams, as after refraction through a rhomb of Iceland spar (650).

Plane Polarized Light.

661. To understand these new properties of light, we may conceive every beam to be hypothetically produced by two sets of undulations, moving in a direction at right angles to each other.* Let fig. 1 represent a section of a beam of common light, consisting of two rays CD, NS, at right angles to each other. Light thus constituted possesses all the properties detailed in the preceding chapters; and when allowed to be refracted through a rhomb of Iceland spar, its rays become separated; one of them, as NS, fig. 3, constituting the ordinarily, and the other, CD, fig. 2, the extraordinarily refracted ray (649). Thus, by refraction through the crystal, the luminous undulations become resolved into two colorless series at right angles to each other; when combined, as in fig. 1, they constitute common light: and when separated, as in figs. 2 and 3, they constitute polarized light, so called because they assume new and peculiar properties with regard to each other, and different refracting or reflecting media.

Fig. 316.



662. The ray NS differs from CD only in position; for by causing them to coincide, as by moving CD (fig. 1), until it coincides with NS, we obtain a ray possessing the same properties, but twice as intense as each separately. Planes passing through CD, NS, are termed *planes of polarization;* and the rays CD, NS (figs. 2 and 3), are said to be polarized in different planes.

If the two separated rays NS, CD (figs. 2 and 3), be reunited, as in fig. 1, they will reproduce *ordinary, common, or unpolarized light;* all these terms being synonymous.

663. From a bare inspection of the above figures (661), we see that polarized light may be obtained from common light in different ways; 1, by turning round one of the rays until it coincides with the other; 2, by passing the light through some substance capable of absorbing or checking one ray and transmitting the other; and 3, by allowing light to be incident on a medium

* This very convenient mode of illustrating the phenomena of polarization is a direct expression of the phenomena of the reflection or refraction of polarized light, according to the direction of the planes, and was first applied by Sir David Brewster.

capable of refracting one ray and reflecting the other. By any of these modes, light polarized in a rectilinear direction and in one plane may be obtained.

664. Polarized light is very conveniently obtained by allowing common light to be incident on a doubly reflecting crystal, as calcareous spar, and allowing it to become divided into two beams polarized at right angles (663) to each other; we can, by sticking a wafer or a piece of black paper over the point of emergence of one beam, obtain a ray of light polarized in a direction perpendicular to that which is checked or absorbed by the wafer. A more convenient mode of procuring a beam of polarized light from this crystal, is to divide a rhomb of calc-spar into two wedge-shaped portions, and then to cement them together with Canada balsam. The layer of balsam thus included allows one of the doubly refracted rays to be readily transmitted, whilst it causes the other to be so far bent out of the course of the former as to be altogether out of the field of vision. This arrangement is known by the name of Nichol's prism.

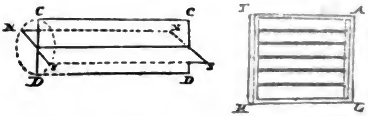
665. When light suffers double refraction through a crystal with a positive axis (653), as quartz, the plane of polarization of the ordinary ray (650) is horizontal, and that of the extraordinary ray vertical. In negative crystals, as Iceland spar, the direction of these rays is reversed. When the plane of polarization of a polarized beam of light is incident in a direction parallel to the principal section (651) of the doubly refracting crystal, it is refracted in the ordinary manner; obeying the extraordinary law when it is incident at right angles to the principal section.

666. When a ray of common light (661) is incident on a thin and transparent plate of agate, cut in a direction perpendicular to its siliceous layers, one of its constituent rays, as CD, (fig. 1, 661), becomes dispersed in a nebulous manner, whilst the other NS is transmitted; the transmitted ray of light being always polarized in a plane parallel to the direction of the siliceous layers of the mineral. A thin plate of agate will also transmit a ray polarized in a direction parallel to its layers, and disperse one polarized in an opposite direction. The direction of these layers may be readily made out even in thin sections of agate by the lines visible in their substance. A plate of agate may thus be employed to furnish polarized light; it does not, however, completely separate a beam of light into two polarized rays, unless it be of sufficient thickness, and the incident light not too intense.

667. The siliceous minerals called tourmalines, especially those of a yellow or hair brown color, when cut into thin plates, separate incident light into the two rays polarized at right angles to each other; one of which is transmitted, and the undulations producing the other are checked or absorbed by the mineral. On turning the plate of tourmaline round through the quarter of a circle, it transmits a beam polarized in an opposite plane to that of the one previously transmitted, and absorbs that ray which it transmitted when in its former position. This action of the tourmaline on light is exceedingly remarkable, for no stratified structure can be detected in these minerals, which, as in the case of agate, would even help to explain their powerful polarizing influence.

668. The action of a tourmaline, or agate plate, on common light, may be familiarly illustrated by fixing two slips of pasteboard in a direction at right angles to each other, as NS, CD, representing respectively the two, hypothetically constituent, beams of common light; let TAKL be a small frame of wood, having a number of wires fixed across it, as shown by the dark lines in the figure. Let TA be supposed to represent a plate of tourmaline or agate, and the paper figure NCDS a ray of light; approach it to TA, in the position shown in the figure, and attempt to thrust it between the transverse bars. The slip of paper NS will readily pass between the wires, but CD will be checked; NS will here represent a transmitted ray of light polarized in a given plane (662).

Fig. 317.

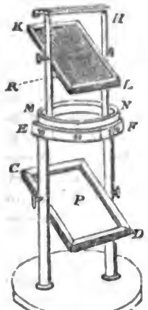


Now turn round TA, until the direction of the wires becomes vertical instead of horizontal, then try to push the paper figure through it; the vertical slip CD will then pass through, and NS will be stopped.

By this little apparatus, the action of polarizing plates of agate or other minerals, acting in the same manner, is readily impressed upon the memory. But it must not be forgotten that the comparison of a set of transverse bars to a tourmaline plate is strictly hypothetical, and although valuable as pointing out particularly the effects of a tourmaline or agate in different positions on a beam of light, yet must not be considered as presenting a correct view of the real *modus agendi* of such polarizing plates on common light.

669. The mode of obtaining polarized light by reflection, was first discovered in 1810, by the celebrated philosopher Malus, an officer in the French engineers. M. Malus, whilst examining the light reflected from the windows of the Luxembourg, through a rhomb of calcareous spar, observed that light, when reflected from the surface of glass at an angle of 56°, acquired the very same properties as one of the beams obtained by submitting light to double refraction in calcareous spar; having, in fact, become polarized, with its plane of polarization parallel to the plane of reflection. This discovery was so quickly followed up by others, and so successfully studied by some of the most illustrious philosophers of the age, that it has led to the development of some of the most beautiful and important series of facts that have ever been discovered. The most convenient mode of repeating the experiments of Malus, is by means of the apparatus figured in the margin.

Fig. 318.



This consists of two uprights of wood, supporting a frame CD, constructed like a common looking-glass frame. A circular plate of wood EF rests on the pillars, and has a circular aperture in the middle about three inches in diameter; a ring of wood MN, movable round a circular projection on EF, supports two pillars GH, between which rests, by means of screws, a frame KL, like CD, but somewhat smaller. A circular slip of paper graduated into 360°, is fixed on that portion of EF which projects beyond MN, a black line being marked on the latter, to serve as an index, and point to zero on the graduated paper, when the pillars GH are exactly over AB, and the frame KL placed so as to regard CD. A plate of glass rests over the aperture in the centre of EF, to serve as a stage on which objects to be submitted to the action of polarized light are placed.

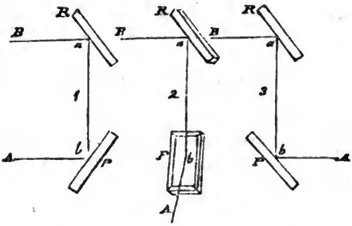
A plate of thin window-glass, blackened at the back with a mixture of lamp-black and size, is fixed in the lower frame CD, and a similar one in KL. The former is termed the *reflecting*, and the latter the *analyzing* plate. As, however, it is of importance to obtain as bright a beam of polarized light as possible, it is better to make the lower frame CD deeper, and to place in it a dozen plates of window-glass pressed together by means of a piece of wood

at the back. The hindmost plate should be blackened at the back. By this contrivance a very bright beam of reflected polarized light may be obtained.

This instrument, which was first suggested by M. Biot,* is the most convenient that can be used for experiments on polarized light; it may be conveniently termed a Polariscope.

670. Place a lighted candle at a short distance from the reflecting plate P, and adjust the latter so that the light may be incident upon it at an angle of 56° 45′. Then by means of the side screws fix the upper or analyzing plate R, so that the ray reflected from P is incident upon that at the same angle of 56° 45′. The sections of the plates showing their relative position are shown in fig. 1. Light, on being incident on P, in the direction AP, is resolved into two portions,† one being polarized in a plane perpendicular to the plane of reflection, and mixed with much common light, passes through the glass P,

Fig. 319.



and is *absorbed*, from the undulations being checked by the black paint with which its back is covered. The other portion, polarized in an opposite plane, is reflected to R, and thence to the eye of the spectator at B, who of course sees an image of the candle in R. Then turn round the plate R, still keeping it at the same angle, by moving the collar MN on the wooden collar EF (669), and when R is at right angles to P, as in fig. 2, the image of the candle will almost entirely vanish. This might be indeed anticipated, for the ray polarized by reflection from P, is reflected polarized in the plane of reflection; and on placing R at right angles to P, the ray passes through the glass, and becomes absorbed by the black paint at its back. So that, on looking at R in this position, scarcely a vestige of light is to be seen reflected from it. On moving R round for another angle of 90°, as at fig. 3, the light and figure of the candle will reappear in R, as the planes of polarization (662) and reflection coincide, being both contained in a plane passing through APRB. At the intermediate arcs of rotation, the light in R will decrease or increase in intensity, according as it approaches or recedes from the position shown in figs. 1 and 3. In these three figures, A*ba* shows the position of the *planes of primitive polarization*, and *ba*B the position of those of reflection.

671. Let R and P be fixed in the position shown in fig. 1 (670), the index on MN will point to zero on the graduated circle (669); and on watching the

* Précis de Physique, tom. ii. p. 475. Paris, 1824.

† It is, perhaps, hardly necessary to remind the reader, that the angles at which light should be incident on reflecting surfaces for complete polarization, are calculated from a line perpendicular to the reflecting surface. On the continent, light is usually directed to be incident upon the reflector at an angle calculated from its surface; hence it will be a number complementary to the true polarizing angle. Thus the angle at which light is polarized by reflection from glass is 56° 45′ measured from a line perpendicular to its surface, and 33° 55′ measured from the reflecting surface itself.

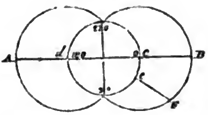
intensity of the light reflected from R, at different azimuths, the following effects will be observed on turning R slowly round:

Inclination of Planes of Reflection, as shown by the graduations on EF.	Varying brightness of an image of the candle reflected from the plate R.
0°	Greatest intensity of light.
0°—90°	Light decreases until it nearly vanishes.
90°—180°	Gradually increases in intensity.
180°	Regains the intensity it possessed at 0°.
18°—270°	Same as 0° to 90°.
270°	As at 90°, scarcely visible.
270—360°	Gradually increases, as from 90°—180°.

The light reflected from R, decreases in the ratio of the squares of the cosines of the angles formed by the planes of polarization and reflection.

672. The intensity of the polarized light reflected in various positions of the upper mirror (669), corresponding to the different angles formed by the planes of reflection and primitive polarization, may be illustrated by the following figure. The lines in the inner circle point out the different positions of the plane of reflection; and the two curved figures AB represent the amount of reflected light.

Fig. 320.



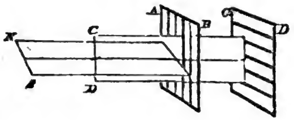
Thus at 0 and 180 the greatest amount of light is reflected, as the lines CB, A*d*, are the longest which can be drawn from the circumference of the inner circle to the limits of the curved figures. At 45°, the intensity of reflected light will be less than at 0, as the line *e*F is shorter than CB, whilst at 90° and 270° it will attain a minimum, as the diameter connecting these numbers, if produced, will not be included in any portion of the curved figures.

673. Thus we see that light reflected from glass at 56° 45′, consists almost entirely of light polarized in one plane, equal to about one-half of the whole of the incident light, and refuses to be reflected from a second glass plate when the plane of reflection is at right angles to the plane of polarization of the ray (662). Hence, as one portion of the incident light only is reflected from one plate, and that becoming absorbed when the second plate is at right angles to the first, it follows that no light ought to be reflected from this plate, if the polarization of the light be complete.

The effects thus observed of extinguishing light, by altering the position of the reflectors, are analogous to those observed by crossing two tourmaline plates. If two similar plates of that mineral be placed together, so that light polarized in one plane can be transmitted, objects may be distinctly seen through them; but on turning one at right angles to the other, absolute darkness ensues, as each plate absorbs the light polarized in different planes. This effect may be readily understood, by placing two gratings, AB, CD, opposite each other, so that the bars of one may be vertical and those of the other horizontal, and attempting to thrust the paper figure, NSCD, through them (668). Although,

when the bars of the two gratings were in the same position, one or other of the paper slips NS, CD, passes through, yet when crossed, they effectually prevent the introduction of either; for one, as CD, although it may pass the first grating, is stopped by the second, whilst the ray NS is checked by the first.

Fig. 321.



674. If one of the beams of polarized light obtained by double refraction (664) be used instead of the light reflected from P (669), it will present the very same phenomena on turning round the plate R, as the light polarized by reflection from P did: the ordinary ray having its plane of polarization vertical, and the extraordinary ray horizontal. If light is polarized by absorption of one of its component beams through tourmaline, or by its dispersion through agate (668), the same effects will be observed; so that in whatever manner light is polarized, it possesses the same properties, providing only its planes of polarization (662) be in the same position. Thus, plates of tourmaline or agate may be used for the purpose of analyzing polarized light, in place of the analyzing plate of the polariscope (669). The analysis being performed by refraction instead of reflection.

675. It has been already stated, that a portion of the light refracted through glass, when incident at the polarizing angle, is partly polarized, and in a plane at right angles to the reflected beam (670). This refracted light may be obtained very free from common light (661), by placing eight plates of thin crown-glass together, and fixing them obliquely in a tube, so that they may be inclined at an angle of 79° to its long axis. On allowing a beam of light to traverse this tube, it will emerge polarized in a plane at right angles to that at which the reflected light is under similar circumstances polarized. A system of plates thus arranged in a tube constitutes a very excellent mode of analyzing light polarized by reflection, and developing the colors of doubly refracting crystals (685). Sir David Brewster has found, that by increasing the number of glass plates, the refracted light becomes polarized at a much smaller angle of incidence; thus, light is completely polarized by refraction through one plate of glass at an incidence of 81° 38′; through two at 87° 16′; through six at 81° 50′; through forty-one at 45°; and through 8,640,000 plates at an angle of incidence of only one second, providing the light be sufficiently intense to penetrate such a mass of glass. The best glass for polarizing light by refraction is that which is used to cover microscopic objects with. It may be obtained of extreme thinness, and is peculiarly valuable for this purpose.

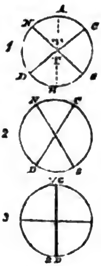
676. If the reflecting plate P (669) is placed at any other angle except that for complete polarization, a certain portion only of reflected light will be polarized. Very different opinions have been hazarded on the nature of this partially polarized light; it has been, by several very illustrious philosophers, considered as made up of common light, mixed with a small quantity of completely polarized light. Sir David Brewster, to whom science is so largely indebted for his investigations on this subject, however, considers that partially polarized, or, as he proposes to call it, apparently polarized light, is light whose planes of polarization are inclined at angles of less than 90°; and he bases this opinion on the fact that light thus partially polarized may, by a sufficient number of reflections, have its planes of polarization turned round so as to coincide, and constitute perfectly polarized light. The following table, given by Sir David,* shows the number of reflections required to completely polarize light at any angle, above or below the polarizing angle, or 56° 45′.

* Optics, p. 173, and Phil. Trans., 1829.

Number of reflections required.	Angles at which the light is reflected.	
1	56·45	——
2	50·26	62·30
3	46·30	65·33
4	43·51	67·33
5	41·43	69·1
6	40·0	70·9
7	38·33	71·5
8	37 20	71·51

677. Sir David Brewster illustrates his position by assuming a beam of common light to be constituted as NS, CD, (fig. 1, 661.) Let such a beam be incident on a reflecting surface, so that the plane of reflection exactly bisects the angle which the two planes of polarization form with each other, as the dotted line AB bisects the angles NTC, and DTS (fig. 1). By reflection from a glass plate, whose index of refraction is 1·525, the inclination NS to AB will be 33° 13′; so that DC will describe with NS angles of 66·26, as in fig. 2. At an incidence of 65, the inclination of NS to CD, will be 25° 36′; and at the polarizing angle of 56·45, the angle of inclination of NS, CD, will vanish, as the two beams are made to coincide as in fig. 3. Thus, at an incidence on glass at any angle differing from the polarizing angle of 56·45, the planes of light, NS, CD, become inclined more and more to each other, in proportion as the incident angle approaches 56·45, at which angle the two planes become so turned round as to coincide completely, and produce a single beam of polarized light.

Fig. 322.



678. In the preceding observations, light is supposed to be polarized by reflection from glass alone; the same physical characters may, however, be communicated to it by reflection from the surfaces of almost any non-metallic substance; as that reflected from metallic surfaces (726) differs in its properties from the polarized light under consideration. All bodies have their peculiar polarizing angle in the same manner as they have their index of refraction; thus, the angle for glass is 56° 45′, and for water 52° 34′. The effects of the different polarizing angles of two transparent substances upon polarized light, may be shown by an experiment described by Sir D. Brewster. Having fixed the plates PR (670, fig. 2) at the angles of 56° 45′, and with the planes of reflection and polarization perpendicular to each other, the image of the candle will be invisible in R. Breathe upon the latter, so as to cover it with a film of water, and immediately the candle will become visible, from a portion of the polarized beam undergoing reflection from the vapor condensed on R.

679. The angle of *complete polarization* for any substance may be readily determined by the law discovered by Sir D. Brewster that—*The index of refraction is the tangent of the angle of polarization.* Thus, if the polarizing angle of water, whose index of refraction is 1·336, be required, all that we have to do, is to look for that number in a table of natural tangents, or for its logarithm in a table of logarithmic tangents, and the corresponding angle of 53° 11′ will be found opposite to either. The polarizing angle of crown glass 56° 45′; for, as its index of refraction is 1·525, the logarithm of that number is 18327,

which is the table of logarithmic tangents, corresponds very nearly to the angle mentioned.

680. Light may be polarized by reflection from the second surface of bodies, or internal reflection; and the angle for complete polarization has its cotangent equal to the index of refraction of the substance, and may be found by looking for the latter number in a table of cotangents. This, in the case of water, will be 56° 49′, and of crown-glass 33° 15′; so that the polarizing angle at the second surface, is equal to the complement of that for the first surface of a medium.

681. If, instead of using white light, any one of the colored beams of the spectrum be incident on a reflecting medium, it will undergo polarization in the same manner as common light, but at a different angle for each ray. The value of the polarizing angle for each, may be found from its index of refraction, by means of the law of tangents (679). Thus, the polarizing angle, when water is used, is 53·4 for the red, and 53·19 for the violet beams; and when plate glass is employed, 56·34 for the red, and 56·55 for the violet.

From the data contained in Fraunhöfer's table, the polarizing angle for each of his seven rays may be readily computed.

682. A considerable portion of light when incident on a single glass plate is refracted through it and lost; consequently when the reflecting surface of a polariscope is composed of but one plate, too small a quantity of polarized light for many purposes is procured. The frame CD (669) should, therefore, contain about a dozen plates of thin glass, instead of only one, and then a very powerful beam of polarized light is obtained; and whenever the polariscope is referred to in the following pages, it is always supposed to contain these number of glass plates in the lower frame. If light be incident obliquely on the first plate of such a series, as at an angle of 74°, the refracted light will be almost entirely polarized, and in a plane at right angles to that of the reflected beam (670). A bundle of plates of mica, or talc of commerce, may be advantageously substituted for those of glass, as they are very light, occupy but little space, and polarize light very effectually.

683. When the sky is tolerably free from clouds, a certain portion of the light becomes more or less polarized in its passage to the earth. The maximum of polarization takes place in a circle placed about 90° from the sun. The plane in which the polarization occurs varies in different parts of the sky according to the position of the sun. According to Arago, the rays reflected from the moon contain a considerable quantity of polarized light.

CHAPTER XXV.

COLORED POLARIZATION.

Interference of polarized light, 684. *Colors exhibited by selenite*, 685—*by mica*, 688. *Cause of these colors*, 687—*always complementary*, 689. *Rings produced by a cone of rays in crystals*, 690—*seen in talc-spar*, 691—*in topaz*, 694—*in mica*, 698—*in Rochelle salt*, 699—*in nitre*, 700. *Mode of analyzing*, 702. *System of tints in unannealed glass*, 703—*in cylinders*, 704—*in square pieces*, 705. *Lines of no polarization*, 706. *Polariscope for doubling the colored lines*, 707. *Colors in jelly*, 708—*in crystaline lines*, 709. *Polarizing microscope*, 710.

684. HAVING described some of the most important properties of white rectilinearly polarized light, we have next to investigate the phenomena of color produced by interference. To appreciate these, the following laws, discovered by MM. Arago and Fresnel, must be previously well understood.

(A.) Two beams of light polarized in the same plane (662) are capable of interfering with each other like common light, and they produce in consequence fringes of the same character.

All the experiments on diffraction (633), if repeated with polarized light, will produce the same phenomena as if common light were used.

(B.) Two beams, polarized in planes at right angles to each other, will *not* by their interference, produce colors. When polarized at angles intermediate, between 0° and 90°, they produce fringes of intermediate brightness, the tints disappearing at 90°, and recovering their vividity at 0°.

(C.) Two beams polarized at right angles, may be brought into the same plane of polarization, wirhout acquiring the power of forming fringes by interference.

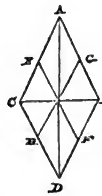
(D.) In the phenomena of interference produced by rays that have undergone double refraction, a difference of half an undulation must be allowed, as one of the beams of light is retarded to that amount by some unknown cause.

685. To exhibit the tints produced by polarized light, place on the glass stage of the polariscope (669), a thin lamina of selenite, of uniform thickness, and allow a beam of light, polarized by reflection from the lower plate P, to pass through it to R. The source of light may be the sun's rays, or diffused daylight, or still better, the light of a lamp or candle provided with a ground-glass shade. Let the index on NM be placed at O on the graduated circle XF, by turning round the former, and the plates RP be placed as in figure 1 (670). Let R and P be fixed at the polarizing angle (679), and on looking into the analyzing plate R, the image of the selenite will be seen, not colorless, but possessing a tint varying with the thickness of the plate. Let us suppose the film of selenite to be of such a thickness as to appear red when its image is viewed in the analyzing plate: slowly turn round the selenite, and the color will gradually disappear and ultimately vanish; at this point the plane of primitive polarization (670) will pass through one of the axes of double refraction (653) of the selenite, and no production of color can ensue. Continue to turn round the selenite, and the red color gradually reappears, attaining eventually its primitive brilliancy; on continuing the rotation, the color again lessens, and disappears when the plane of polarization

passes through the second neutral axis of the crystal. The greatest intensity of color will be observed when one of two lines, inclined 45° to the neutral axis, lies in the plane of primitive polarization; these lines are termed *depolarizing axes*, because they alter the polarization of the transmitted light.

The position of these lines are observed in the following figure:

Fig. 323.



CABD, the plate or film of selenite.

EF, GH, neutral axes at right angles to each other.

AD, CB, depolarizing axes, inclined to EF, GH, at angles of 45°.

686. Having again placed the plates of the polariscope as at the commencement of the last experiment, let the film of selenite remain fixed, and when its red image is visible in the analyzing plate, slowly revolve the latter, noticing the arcs of rotation on the graduated circle. On revolving the analyzing plate, the red color of the reflected image will gradually lessen, and when a revolution through 45° has been performed, it will disappear; after 45° the film will gradually assume a green color complementary (614) to the red; and will attain its greatest brightness at 90°. From 90° to 135° the green vanishes, and after 135° the red reappears, attaining its utmost vivid state at 180°, after which it again vanishes; at 270° acquiring its green color, which, on continuing to turn the plate, vanishes at 325°; ultimately becoming red at 360° or 0°, from which point we set out. If the plate of selenite had been of such a thickness as to afford other tints, the complementary colors would have appeared as in Newton's experiments, with the colors of thin plates (641); the colors seen at 0° and at 90°, or 180° and 270°, being invariably such as, when united together, would constitute white light.

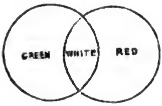
687. If the analyzing plate of the polariscope be removed, and the selenite be viewed with the naked eye whilst the polarized ray is passing through it, no colors will be seen. Hence the analyzing plate must have aided in rendering them visible. To understand this, let us follow the course of a polarized ray passing through a plate of selenite at or near one of its depolarizing axes. The selenite being a doubly refracting crystal, will cause the incident polarized ray to be divided into two, an *ordinary* and *extraordinary* (650) polarized in different planes, which reach the eye together, and a colorless image is perceived. But if the analyzing plate be used, and the light which has traversed the crystal be reflected thus to the eye, an important change occurs, the white image is broken up into two colored ones complementary to each other, one of them, as the green one, is polarized in the plane of reflexion, and therefore reaches the eye, giving a green image of the selenite. The other image being polarized in a different plane, passes through the analyzing plate, and by looking *through* the latter whilst inclined at a considerable angle to the ray, a red image of the selenite is visible, the same thing occurring by reflexion if the analyzing plate be revolved 90°, as then the plane of reflexion will coincide with the plane of polarization of the red, and differ from that of the green ray.

688. If a thin plate of mica be placed on the stage of the polariscope, instead of the selenite, colors disappearing and reappearing in the same manner will be seen. And on inclining the mica, so that the polarized ray may pass through different thicknesses of it, a variety of exquisitely beautiful tints will become developed. If the mica or selenite be not of uniform thickness, the reflected image will appear richly tinted with various hues, depending for their variety and intensity upon the varying thickness of the plates.

689. A very instructive mode of analyzing the polarized ray after it has passed the film of selenite, is to view the latter through a doubly refracting

rhomboid of calc-spar; the transmitted ray will be divided into two colored images which will be both visible at the same time. The red and green images are complementary to each other, and if superposed would constitute white light. This may be proved by holding the calc-spar at a proper distance, when the two images will partly overlap, producing white light, as in the accompanying figure. On this account no colors were seen when the selenite was viewed without the analyzing plate (687) or calc-spar, as *both* rays then reached the eye together, and produced a white image.

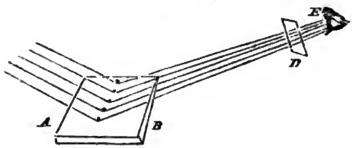
Fig. 324.



690. In the above experiments with selenite or mica, the rays of incident polarized light were nearly parallel; if, however, they are converging and enter a crystal so as to traverse its optic or doubly refracting axis (653), a new and splendid series of phenomena become visible.

Let common light be incident on a plate or a series of plates of glass, AB, placed on a black surface at the polarizing angle, so that a bright beam of polarized light may be reflected to the eye at E, which thus is placed at the

Fig. 325.



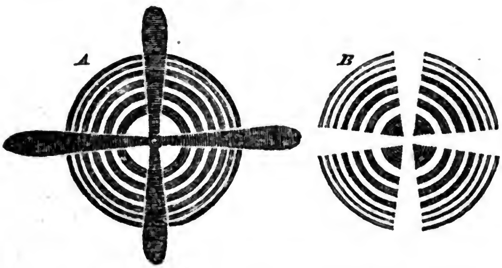
apex of a cone of rays. If a thin plate of a doubly refracting crystal, as calcareous spar, cut at right angles to its axis, be placed at D, it is obvious that the rays of polarized light will traverse it with various degrees of obliquity, and thus virtually permeate different thicknesses of the section. The central rays which pass through the optic axis do not suffer double refraction, and therefore will appear to the eye at E, the same as if no crystal had been present, but the other rays which pass through the other portions of the crystal will undergo double refraction, each being resolved into an ordinary and extraordinary ray, as in the case of the plate of selenite (687). These rays, however, reaching the eye together, will not produce any color, and cannot be distinguished from common light. To render the phenomena of colored polarization obvious, an analyzing eye-piece must be placed between the plate of doubly refracting crystal and the eye. Let this be a plate of tourmaline (667) or agate, so placed as not to transmit the polarized light reflected from AB, if the crystal D were absent. It will be found that the light reflected from AB has undergone some physical change whilst traversing D, as some of it has acquired the power of passing through the analyzing plate of tourmaline, and a beautiful, symmetric image, painted with the most gorgeous colors, becomes visible. This image is composed of a series of concentric colored curves, and traversed by a black cross. Let the tourmaline be then turned round 90°, and an image complementary to the first will be visible, its black cross being replaced by a white one.

691. The origin of these beautiful colored rings is easily explained. The rays which do not pass through the optic axis, or those parts of the crystal destitute of double refraction, are divided into two pencils, an ordinary and extraordinary polarized in different planes, and hence one series are absorbed and the other

transmitted by a tourmaline plate, according as it is held so as to transmit or absorb the originally polarized ray; but this, although sufficient to explain the productions of two images, is not sufficient to explain the phenomena of colored rings. It must be recollected that the rays pass through the plate of the crystal D with various degrees of obliquity, and hence some suffer more in the rapidity of their motion than others, or, in other words, undergo a different amount of retardation. The rays are thus placed in the very condition required for the phenomena of interference and consequent production of colored fringes, as in the case of common light. The ordinary rays being polarized in the same plane, they mutually interfere to produce one of the colored images, and the extraordinary interfere to produce the other. Both images being complementary to each other, and if superposed produce white light. The figure of the rings results from the rays which penetrate the crystals at equal distance from the optic axis, passing through similar thicknesses of the plate, and consequently undergo the same amount of retardation, and produce similar tints at equal distances from the centre. The singular appearance of the black cross is owing to the rays which traverse the crystal in a direction parallel to its principal section (651) as well as in one perpendicular to it, emerging unchanged, and in these two directions the dark blue or black appearance presented by the reflector AB (690), when viewed through the analyzer, will be visible as the arms of a black cross.

692. To examine these rings in uni-axial crystals, take a crystal of calc-spar, and cut from it a thin plate at right angles to its axis (654). This should be preserved from injury by securing it by means of Canada balsam between two thin plates of glass. If such a plate be held near the eye in the manner above described, a splendid series of colored rings, resembling those of Newton (641), will be visible, the whole being intersected by a black cross, corresponding to the lines of no-polarization in the crystal, or those along which the polarized ray reflected from AB (699) passes unchanged. The arms of the cross end in brushes, and appear to extend for a considerable distance. Fig. A shows this beautiful figure.

Fig. 326.



Let the eye-piece be then revolved through 90°, so as to transmit the light reflected from AB, the figure B will then be visible, all the colors in the rings of which are complementary to those in A, and a white cross takes the place of a black one.

693. If the plate of calc-spar be revolved on its axis, no change whatever occurs in the rings, and if a portion be covered up with a piece of black paper, the uncovered portion of the plate will exhibit the rings as perfectly as the

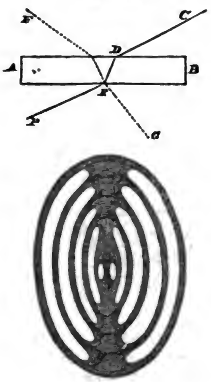
whole plate. This may be readily understood by recollecting that the axis of double refraction in these crystals is not a fixed line, but merely a fixed direction (653), and exists as completely in the smallest fragment as in a large plate of a crystal. If the plate of calc-spar be thicker, the rings will appear wider and less closely packed together.

694. If a similar plate be cut from any other uni-axial crystal, it will exhibit the same beautiful rings when held in the course of the beam of polarized light. If a crystal with a positive axis of double refraction, as zircon or ice, be examined, the rings will be identical with those of calc-spar which has a negative axis. But if a plate of zircon be placed on one of calc-spar, and the combination be examined, they will be found to obliterate each other's tints so that, if of proper thickness, no colored image will be visible.

695. If, instead of allowing common white light to be incident on the polarizing reflecting plate AB (690), homogeneous light be substituted, the same phenomena will be observed as when white light is used, but the rings will be alternately black and of the same color as the light employed. An alteration in their size is also of constant occurrence, the rings being largest in the most refrangible or violet light, and smallest in red light.

696. In crystals possessing two axes of double refraction including by far the greater proportion of natural and artificial crystalized products, somewhat different phenomena are observed, of which the tendency to ellipticity in the rings, and presence of a black bar across them, constitutes the chief. In bi-axial crystals, where the axes are at a very small angular distance from each other, both systems of rings may be observed at once, one around each axis, as in nitre, arragonite, and some specimens of yellow prussiate of potass (ferro-cyanide of potassium). In the great majority, however, the axes are so far dispersed that but a single system can be seen at a time, and two distinct sections, each made nearly perpendicular to either resultant axis, is necessary for showing them.

Fig. 327.

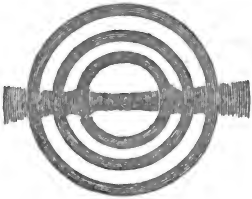


697. Let AB be a plate of Scottish topaz, cut at right angles to the crystallographic axis of the crystal. This is bi-axial, the resultant axes being inclined about 65° to each other. Let a ray of polarized light FE be incident obliquely on this crystal, and view it by means of a tourmaline eye-piece in the direction CD. An elliptic system of rings, traversed by a black bar, will be visible, providing the eye piece be so placed as to absorb the original ray before traversing the crystal. If the plate be then altered in position so that the polarized ray may pass in the direction GEF, a second system of rings precisely similar to those visible along CDF, will be visible. Thus FEG and CDF represent the direction of the two axes of the plate of topaz. If the eye-piece be revolved through 90°, a figure complementary to the last will be observed, all the red rings being replaced by green, &c., and the black bar by a white one.

698. The rings in bi-axial mica can be readily discovered by holding a piece of the ordinary *talc* of the shops about ⅛ inch thick, in an inclined position as near to the tourmaline eye-piece as possible, and allowing a ray of polarized light to pass through it. But one system is visible at a time, as the axes are so much in-

clined to each other. If the rings are not at first visible, they readily become so by moving the mica. The figure is generally circular, as in the adjoining figure, and traversed by a black bar, which becomes replaced by a white one, when the complementary figure is obtained by revolving the eye-piece round 90°. Plates of borax or sugar-candy cut perpendicular to one of the optic axes, may be conveniently used to exhibit these rings.

Fig. 328.



699. In most bi-axial crystals, in which the angular distance of the axes is considerable, the system of rings is always elongated into an elliptical figure (696), and the tints are not arranged with the symmetry we meet with in crystals with one axis. This is beautifully shown in sections of the Rochelle salt, the potassio-tartrate of soda. If a plate cut transversely to one of the axes of this salt, (in the manner described in the case of nitre,) (700) is examined by polarized light, a splendid elliptic system of rings, traversed as usual by a black or rather a deep blue bar, will be observed. These rings are most gorgeously tinted, but the colors are not equally arranged, the red predominating at one end of the long axis of the ellipse, and green or blue at the other, adding, indeed, much to the beauty of the figure. In some crystals, presenting these phenomena, the red ends of the rings are within the resultant axes, whilst in others the blue ends are thus placed. To the former belong phosphate of soda, sugar, carbonate of lead, &c., whilst the Rochelle salt, sulphate of magnesia, and topaz, afford examples of the latter.

700. When the inclination of the axis is small, both systems of rings can be seen at once. To show these, take a crystal of nitre, and by means of a fine saw, cut off a plate half an inch thick, at right angles to the long axis of the prism. The best mode to render this sufficiently thin, is to rub it on a fine file immersed in water. A plate of one-sixth of an inch in thickness can thus readily be procured, and should be preserved between plates of glass like the calc-spar (589). In general these sections of nitre are only perfectly transparent at their margins, being opaque and perforated in the centre. This is, however, of no consequence, as the transparent edge shows the rings very beautifully. For this purpose, the plate should be held in the course of the polarized ray, as near as possible to the eye, armed with a tourmaline. The

Fig. 329.

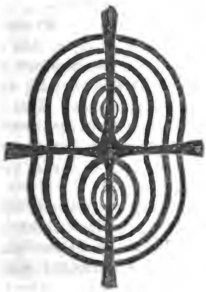


Fig. 330.

beautiful figure shown in the margin will be visible, or will readily become so, by slightly altering the position of the plate. The two systems of rings are beautifully distinct and splendidly colored; the outer rings of both systems coalesce and surround the whole figure with a sort of elliptic border. If, whilst the eye-piece is fixed, the plate of nitre is slowly revolved, the black arms of the cross will open, and when the line connecting the two axes of the crystal is inclined 45° to the plane of primitive polarization, the image figured in the margin will be seen, in which the cross is replaced by two hyperbolic curves. If the plate of nitre be fixed, and the analyzer be revolved, a figure complementary to the first will be seen. The black crossed lines being replaced by white spaces, and the red rings being replaced by green, the yellow by indigo, &c.

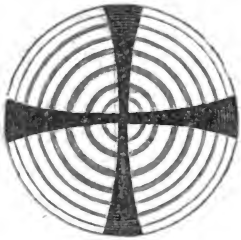
701. The double system of rings may often be finely seen in yellow prussiate of potass. This salt is laminated and readily splits in the direction of its layers. A piece should be then removed about a quarter of an inch thick, and if not quite smooth, should be polished by friction against a piece of wood moistened with water. By holding such a piece in the direction of a polarized ray, and analyzing it with a tourmaline, a fine double system of rings will be often seen. No salt, however, varies in the inclination of its axes so much as this: in some specimens they are nearly merged into one, so as to be virtually uni-axial, whilst in others they are considerably dispersed.

702. The analysis of the depolarized rays transmitted by these crystaline plates, may be effected not only by absorption of one series through tourmaline, or their dispersion through agate (666), but may be as well effected by using for an eye-piece a series of inclined glass plates (676), or a single image prism (664). The field of view is, however, more limited than when a thin plate of tourmaline is used. The analysis may also be conveniently made by reflection from a glass plate, which should be as small as possible. A piece of black glass, one-fourth of an inch in diameter, fixed to a little arm of brass, so as to allow of its being inclined at any angle, and revolved on its axis, constitutes a convenient form of analyzer; indeed, was the one used by Sir David Brewster in his elaborate researches on the rings of crystals.

703. By means of the property possessed by polarized light of developing these colored rings, which always in tint and arrangement bear a constant relation to the physical structure of the crystal producing them, we are enabled frequently to make out the existence of peculiar and intimate arrangement of molecular structure; and thus acquire a new and powerful mode of investigating the internal arrangement of some of those simple but wonderful structures presented to us so liberally in both the organic and inorganic world. This may be beautifully illustrated by subjecting unannealed glass to the action of polarized light; we have seen that glass, by suddenly heating or cooling, acquires the property of double refraction (659). If the glass be properly prepared, by heating it red hot, and rapidly cooling it, this doubly refracting structure is permanent. Such a piece of glass appears, when viewed by ordinary light, like any other; nor can any peculiar feature be detected in it, in which it differs from other specimens of that substance. But if a piece of this prepared glass be placed on the stage of the polariscope (669), a most beautiful colored image will become visible in the analyzing plate; whilst, under similar circumstances, the glass before heating did not exhibit the slightest color.

704. A solid cylinder of glass carefully heated and cooled quickly, is generally found to be uni-axial, and when examined by polarized light, by placing it on the stage of the polariscope, the planes of reflection and polarization being at right angles; the system of rings shown in the marginal figure much resembling those seen in calc-spar will be visible. The axis of double refrac-

Fig. 331.

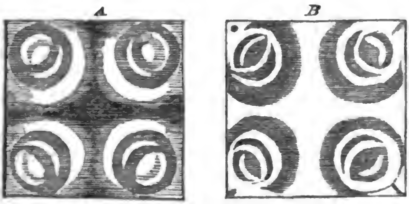


tion is, however, generally somewhat eccentric, so that on revolving the cylinder, a slight tendency to distortion in the arms of the cross is observed. There is this essential distinction between the rings visible in unannealed glass, and those in natural or artificial crystals, that in the latter they may be detected in the minutest particle, so that if any part of the crystal be covered up, the uncovered portion (693) will show these rings as perfectly as the whole crystal. On the other hand, if any part of a piece of unannealed glass be covered with black paper, a corresponding portion of the rings and cross developed polarized light will cease to be visible.

705. Let the planes of the polarizing and analyzing plates be at right angles (670, fig. 2), the index being at 90, and if the glass be shaped into a cube, the beautiful figure shown at A will appear. The circular curves in the angles possess the most vivid hues, in which red and green predominate; the centre being occupied by a black cross.

On turning the analyzing plate round 90°, so that the planes of reflection and polarization may coincide (670, fig. 1), the colors, which almost entirely vanish at 45°, will undergo a remarkable change; the figure shown at B will appear, all the colors of which are complementary to those of A, and the black cross will be replaced by white spaces.

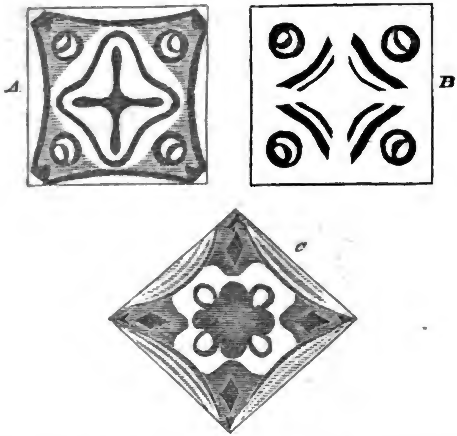
Fig. 332.



If the plate of unannealed glass be square, and about one-third as broad as it is long, the elegant figure shown at A will be visible when the analyzing plate is set at 90°, so that the plane of reflection may be perpendicular to the plane of polarization. The complementary figure B, replacing it when the analyzing plate is placed at 0° or 180°, so that the planes of reflection and polarization correspond.

706. The dark lines forming the black cross, seen when these plates are submitted to polarized light, must be considered as pointing out the position of the points where the polarized ray passes through unchanged, and are hence conveniently called *lines of no polarization* (691). If the analyzing plate be fixed, and the unannealed glass be slowly turned round, the black cross will begin to open, and its arms to separate in elegant curves, until its resultant axes (653) are inclined 45° to the planes of polarization and reflection, when a beautiful symmetrical figure will be visible, as at C in the last figure. On continuing to turn the plate of glass the dark cross gradually

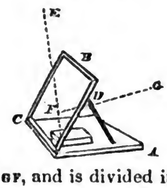
Fig. 333.



re-appears, and attains its greatest intensity when one of its arms corresponds to the plane of polarization, and the other to that of reflection.

707. The beautiful figures thus visible in unannealed glass are rendered more brilliant by allowing the polarized ray to pass twice through the piece submitted to experiment. For this purpose, the very simple apparatus for polarizing light proposed by Lecount, can be conveniently employed. It consists merely of a small-looking-glass A, placed on the table, a frame B fastened to the mirror by a hinge at C, has about ten plates of common plate window-glass placed in it, and is fixed in an inclined position to the mirror, by means of a support D. The piece of unannealed glass is placed on the mirror, and it is viewed in the direction EF, and the figures become beautifully distinct, the rings being much more numerous than when examined in the ordinary manner. Common light is incident on B in the direction GF, and is divided into two oppositely polarized rays; one is transmitted and the other is reflected towards the mirror, passing in its course through the unannealed glass; from the mirror it is reflected back again, passing through the latter, and being partly depolarized, passes in part through the inclined glass plates, rendering the figure visible at B.

Fig. 334.



708. When a mass of animal jelly is placed on the stage of the polariscope, no colours are visible in the analyzing plate, so long as the jelly is not submitted to pressure; but as soon as it is compressed with sufficient force, it assumes a doubly refracting structure, and a series of tints traversed by a black cross becomes visible, providing the analyzing plate be so placed that the planes of reflection and polarization are at right angles.

Jelly, solutions of gum, and albuminous fluids, allowed to evaporate spontaneously, so as to leave an indurated mass, also exhibit the four colored sectors, traversed by a black cross. A slip of glass, previously without action

on polarized light, develops a seriés of tints, by bending it or submitting it to pressure.

709. No series of objects exhibits the tints of polarized light more beautifully than the crystaline lenses of animals, especially of fishes; to examine these, they should, to prevent their bringing the incident rays to a focus, be immersed in a glass vessel, containing oil, or some fluid possessing nearly the same refractive power as the lens. The crystaline lens of the cod-fish exhibits twelve beautiful colored sectors, separated by two dark concentric circles of no polarization (663), and traversed by a black cross.

Fragments of ordinary quills, and other indurated animal structures, also exhibit these tints, when submitted to the action of polarized light, in an extremely beautiful manner.

710. Most interesting results are often obtained by examining sections of organized structures or minute crystals in a polarizing microscope. All that is required for this purpose is to place under the stage of an achromatic microscope a single image prism (664), plate of tourmaline (667), or bundle of glass plates. By one or other of these contrivances the light transmitted through any object on the stage will be rectilinearly polarized. The analyzer should be a short Nicol's prism, fixed over the diaphragm in the body of the microscope, or as these must interfere with the achromation of the instrument, a thin plate of brown tourmaline may be placed over the eye-glass. In this way the structures of quills, horns, hoofs, teeth, and other animal structures, are most beautifully developed.

711. A magnificent class of objects for the polarizing microscope is found in crystals of different doubly refracting bodies deposited on glass plates by allowing their dilute watery solutions to evaporate spontaneously. To preserve them, they should be covered with a second plate of glass, some Canada balsam being allowed to run between them. Chlorate of potass, nitre, salicine, acetate of lead, sulphate of copper, and ferrocyanide of potassium, are objects of really gorgeous beauty when thus examined. Some bodies exhibit the colored rings, traversed by a black cross, like calcareous spar (692), and are peculiarly beautiful. The spherical crystals of carbonate of lime, which I discovered to be spontaneously deposited in abundance from the urine of the horse, finely exhibit these. A rare salt, the oxalurate of ammonia, beautifully exhibits the same phenomena. Starch, especially of the potato and *tous les mois*, shows the black cross well defined.

CHAPTER XXVI.

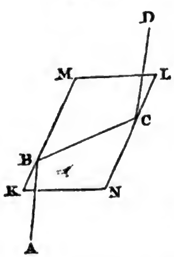
CIRCULARLY AND ELLIPTICALLY POLARIZED LIGHT.

712. When two systems of undulations of equal amplitude, and polarized in planes at right angles to each other, differ in their paths by a quarter of an undulation, the compound movement thus generated in each molecule of ether, will not be rectilinear, as in the variety of polarized light we have just examined, but circular. When the set of undulations which is in advance of the other by the fourth of an entire wave, has its plane of polarization to the right of that of the latter series, the motion will be propagated from right to left in a spiral direction, and from left to right when the system of waves are arranged in the opposite direction, and the resulting light takes the name of dextro-gyrate or right-handed, and lævo-gyrate or left-handed, according to circumstances.

713. This condition of polarized light may be produced in several ways; perhaps the readiest is that proposed by Mr. Airy. He allows a ray of plane polarized light to be transmitted through a lamina of mica or selenite of sufficient thickness to retard the ordinary ray (687), an odd or even number of quarter undulations more than the extraordinary ray. Under these circumstances, the emergent light will be circularly polarized.

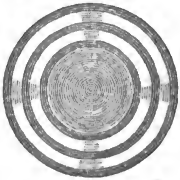
Another process is that of M. Fresnal, by allowing a ray of plane polarized light, AB, to suffer two reflections from the internal surfaces of a parallelopipedon of crown-glass, where acute angles, KL, are inclined at 54·30, and when obtuse ones, MN, are equal consequently to 126°. The emerging ray CD will be circularly polarized. The plane of reflection BCD should form an angle of 45° to the plane of polarization of the ray AB. By each of these internal reflections, a retardation of one-eighth of an undulation is produced in one of the systems into which the incident light is resolved on reflection at the internal surface KM. If the mass of glass be of sufficient length, the ray will emerge polarized circularly after two, six, ten, fourteen, &c., reflections, and rectilinearly after four, eight, twelve, sixteen, &c., reflections. Circularly polarized heat may be readily distinguished from the rectilinear form by examining it with an analyzing eye-piece (702). For it will merely gradually decrease in intensity as the latter is revolved to the right or the left, never disappearing and reappearing four times in each revolution (671).

Fig. 335.



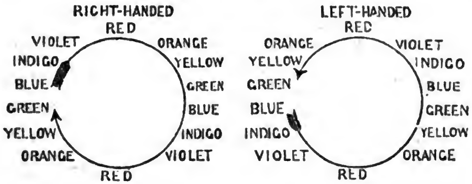
714. Let a plate of regularly crystalized quartz be cut in a direction perpendicular to its axis, and placed on the stage of the polariscope; on looking into the analyzing plate, no black cross will be visible as in calcareous spar, unless the plate be exceedingly thin, and then if held near the eye in the manner already described for examining crystals, a bluish ill-defined cross will be seen. Colored rings are not generally visible unless the plate is held near the eye, so as to be at the apex of a cone of rays (690). When examined on the stage of the polariscope, or at some distance from the eye, the whole plate presents an uniform tint; and no rings will be seen at the circumference of the crystal, the whole being filled up by an uniform tint, providing the plate be of the same thickness throughout; otherwise it will vary, as the intensity of color depends on the thickness of the plate. If the color be red, slowly revolve the analyzing plate, and the tint will change to orange, yellow, green, and ultimately to violet; as though the analyzing plate had during its rotation acquired the power of reflecting these different colors.

Fig. 336.



In some specimens of quartz, and other crystals possessing this power of circular polarization, the colors change from red to violet, when the analyzing plate is turned from right to left, and in others when it

Fig. 337.



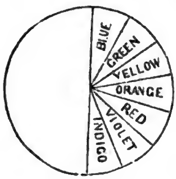
is moved from left to right. Hence these crystals are termed right-handed or left-handed, according as they possess the property of causing the planes of polarization to revolve spirally in a direction from right to left, or left to right (712).

715. A plate of left-handed quartz, 0·3 inch thick, when placed on the stage of the polariscope, so that a polarized ray may pass through it, appears of a fine blue, when viewed through a plate of tourmaline, or bundles of mica or glass plate (702), held in such a manner as to prevent the ray from being refracted through them before being transmitted through the crystal. On turning the quartz round on its axis, no change of color ensues: but on moving the eye-piece of tourmaline, glass plates, &c., the following changes of color are observed at different azimuths:

Azimuth.	Color of transmitted image.
0 . .	. . Fine blue
28 . .	. . Pea green
73 . .	. . Greenish yellow
98 . .	. . Tawny orange
115 . .	. . Vivid red
145 . .	. . Violet
180 . .	. . Rich blue

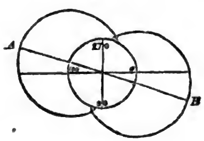
The phenomena thus observed, are the same as would necessarily occur, if the polarized light had been, by passing through the quartz, resolved into a series of homogeneous rays, and become disposed in different planes radiating from the centre of a circle, as shown in the marginal figure representing Newton's chromatic circle, in one-half of which the colors of the spectrum (510) are arranged. The thicker the plate of quartz employed, the greater is the arc required to effect the conversion of the image into one of a different tint; so that, although in the above experiment a rotation of the analyzing eye-piece through an arc of 180° was sufficient to develop a series of colored images, yet, on increasing the thickness of the plate, a much larger arc is required to produce the same effect.

Fig. 338.



716. In plane polarized light we have seen that the maximum and minimum of light reflected by the analyzing plate (671) is attained when the plane of reflection is inclined to that of polarization at angles of 0° and 90°. This, however, is not the case with circularly polarized light. To make this intelligible, place on the stage of a polariscope a plate of right-handed quartz 0·04 inch thick, and illuminate it with homogeneous light, as by that transmitted through a piece of red glass. The greatest intensity of the light will not be any longer at 0° and 180° but at 19° and 199°, and the least at 109° and 289° instead of 90° and 270°, as if the plane of polarization had been turned round 19 degrees towards the right. This may be illustrated by a curved figure like that before employed (672). We see that the lines produced from 0° and 180° are not now the longest that can be drawn within the external curves, but that lines having this property must now be drawn 19° to the right of their former position, or in the direction of the dotted line AB.

Fig. 339.



717. If homogeneous light of other tints had been employed, a still greater alteration in the position of the plane of polarization would have been observed; thus, for the mean rays with a similar plate of quartz, the deviations of the plane amounted, from Biot's experiment, to the following extent:

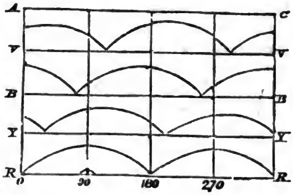
Red . .	19°	Blue . .	32°
Orange .	21	Indigo .	36
Yellow .	23	Violet . .	41
Green .	28		

This alteration in the position of the planes increases with the thickness of

the plate of quartz. Thus, if a deviation of 19° is produced by a plate of quartz 0·04 inch thick in red light, one of 38° is produced by a plate 0·08 inch thick, and of 95° by one 0·20 inch thick.

718. The colors visible by polarized light in quartz are never simple when white light is used; for as the different colored rays are thus shown to be unequally dispersed, it follows that although an excess of one tint may be visible at a time, so as to give a well marked color to the transmitted rays; yet it must in every case be a mixture of several. To comprehend this, let the series of curves in the figure AC RR, represent the intensities of RR the red, YY the yellow, BB the blue, and VV the violet ray respectively.

Fig. 340.

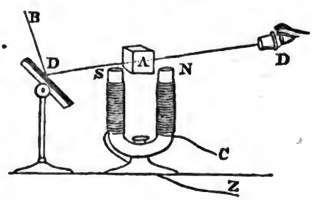


Let a plate of right-handed quartz 0·2 inch thick be then examined by polarized light, the analyzer being so placed as not to reflect the polarized ray, if the quartz were absent. If homogeneous light be employed, the red ray will obtain its greatest intensity at 95° and 275°, and its least at 5° and 185°, the depth of the curves on the line RR being the greatest at the former number and least at the latter. In the same manner the curves on the line YY, BB, and VV, represent the intensity of the yellow, blue, and violet rays at different angles.

Let homogeneous be replaced by white polarized light, and the tints produced by its passage through the quartz plate be observed at 0°; on referring to the figure, the blue and violet rays will predominate, the yellow and red being sparingly reflected; at 5°, the red attains its minimum, and the image will be the darkest from the presence of excess of violet light. At 95°, red will predominate in the image, but mixed with much yellow light; at 115°, the yellow will attain its greatest intensity, at 160° the blue, and at 205° the violet will be at their maximum. Thus, in no case can a pure homogeneous tint be obtained when white polarized light traverses quartz, all the colors being mixtures of several, of which, however, one predominates over the others.

719. One of the most interesting contributions to science, for which we are indebted to Dr. Faraday, is the discovery of the excitement of a molecular change in certain forms of glass, water, alcohol, oil, and other substances when under the influence of the magnetic and electric forces, sufficient to cause the rotation of a polarized ray. To show this with the magnet a piece of flint-glass, A, or much better, a heavy slip of fused borate of lead 2 inches square and 0·5 inch thick, is placed between the poles NS of a powerful electro-magnet (483), so that the lines of force (252) may pass through its length. A ray of light BD is polarized in a vertical plane by reflexion from a piece of blackened glass D, and passing through the glass A is examined at D through a Nicol's prism (664). So long as the bars N and S are not magnetic, the ray is transmitted or extinguished as usual during the revolution of the prism. Let this be then turned so that the ray is darkened, connect the wires CZ with the battery, the bar instantly becomes magnetic and the ray becomes visible. It will be necessary to revolve the prism to the right to extinguish the ray which has, under the influence of

Fig. 341.



the developed magnetism, been made to revolve. If the north pole be next the observer, the ray will revolve to the right, but if this position be reversed, it will revolve to the left

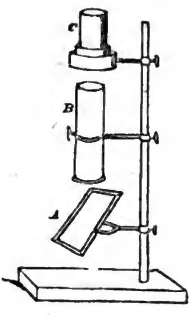
720. When a glass tube is filled with water and placed in the axis of a long helix of wire traversed by a current from a battery of ten pairs of plates, the water assumes a similar rotatory power over a rectilinearly polarized ray, turning it to the right or the left, according to the direction of the current, the ray always revolving in the direction in which the positive current traverses the wire of the helix. When a wide tube of glass is filled with water and the helix traversed by the current immersed in it, the water in the centre of the helix will alone exert any action on a transmitted polarized ray, that lying between the exterior of the coil and the side of the tube having no rotatory power. A piece of borate of lead glass placed in the helix acquires a similar power. Thus by the magnetic and electric forces Dr. Faraday communicated temporarily to glass the rotatory power naturally possessed by quartz (714), and to water and other fluids the power proper to syrup and oil of turpentine.* The intensity of this acquired power is shown in the following table:

Oil of Turpentine	11·8	examined naturally.
Heavy glass	6·0	examined under the influence of electric currents.
Flint glass	2·8	
Rock salt	2·2	
Water	1·0	
Alcohol	less than water	
Ether	less than alcohol	

721. Solutions of sugar, camphor, and a large number of organic fluids, naturally develop the phenomena of circular polarization. If a brass tube, closed at the lower end with a plate of glass, and about six or eight inches in length, be filled with oil of turpentine, and placed on the stage of the polariscope, the richly colored images (715), and a rotation of the plane of polarization from right to left, will be observed.

It is far better to examine the circularly polarizing power of fluids by means of a polariscope constructed for that purpose. The following is a very simple one, which I have used for some years, consisting of a bundle of plates of window glass A, as a polarizing mirror, fixed to an arm so as to admit of ready motion, and supported by a screw from a common retort-stand. A tube of brass an inch in diameter, and eight inches long, B, closed at its lower end with a plate of glass holding the fluid to be examined. The transmitted ray is analyzed by an eye-piece C, consisting of a single-image prism (664), or bundle of thin glass plates (673), capable of being placed at any azimuth. The action of the oil is much less intense than that of quartz, in the proportion of 1 to 68·5: hence the necessity of using a tube full of the oil, so as to form a fluid column about six or eight inches thick.

Fig. 342.



722. Some organic products turn the plane of polarization from left to right, others from right to left (712); this is best seen by using homogeneous light, which for practical purposes may be effected with sufficient accuracy, by observing the rotation through a piece of glass colored red by protoxide of copper,

* Phil. Trans., 1846, p. 14.

and which allows scarcely any except the extreme red rays to pass through it. By operating in this manner, M. Biot* has succeeded in detecting the property of circular polarization in an immense number of fluids, and he has even applied this property to organic chemistry, as a mode of distinguishing between closely allied organic products, as the different varieties of gums and sugars. In the following table are the results of some of the most interesting results of Biot's experiments; the position of the points of the daggers in the third column indicates the direction of the rotation of the planes of polarization *observed through red glass.*

Name of Fluid.	Arc of rotation observed through red glass.	Direction of the rotation.	Thickness of column of fluid in inches.	Specific gravity of the fluid.
Oil of turpentine	45°	—+	6·	
Oil of citron	84	+—	6·	
Oil of bergamotte	29	+—	6·	
Oil of anise	(?)	—+	6·4	
Oil of caraway	100	+—	6·	
Oil of spearmint	(?)	—+	6·	
Oil of rue	(?)	—+	6·	
Naphtha	12° 40′	—+	6·4	
Sol. of cane-sugar in water .	23 5	+—	6·	1·1052
Ditto	51 1	+—	6·	1·2310
Sol. of sugar of milk in water .	10 3	+—	6·	1·0537
Sol. of sugar of starch in water .	48 5	+—	6·	1·2459
Syrup of grape sugar . .	(?)	—+	6·	
Sol. of mannite in water . .	insensible	(?)	9·	
Grape juice	6°	—+	6·3	
Apple juice	3 33	—+	6·3	
Sol. of tartaric acid in its own weight of water . . .	8 5	+—	6·3	

723. A solution of one part of common white sugar in four parts of water was placed in the tube so as to form a column seven inches long; on transmitting a polarized ray through it, and analyzing the refracted light by an eye piece of glass-plates or calcareous spar, placed so as to reflect or disperse the ray, if the syrup had been absent, I found the following to be the tints of the transmitted images at different azimuths:

Azimuth.	Color of Image.
0 ...	Pea-green.
55 ...	Rich blue.
80 ...	Very dark purplish violet.
95 ...	Bright reddish violet.
132 ...	Fine orange.
200 ...	Rich deep blue.

* Mém. de l'Acad. Royale des Sciences de l'Institut., xiii., pp. 39, 176, *passim.*

724. To apply the property of circular polarization to establishing distinctions between closely allied organic products, and to the detection of differences of molecular arrangement in bodies composed of the same elements in nearly similar proportions, it is necessary to determine what M. Biot has termed the *force of their molecular rotation.* This force is nothing more than a comparative expression of the circularly polarizing powers of bodies when reduced to an unity of density and thickness; the unity of thickness assumed by M. Biot is the millimetre, equal to 0·03937, or nearly 0·04 inch. The formula deduced from these interesting researches is of great value, as affording a simple mode of discovering the molecular circularly polarizing, or rotating force, of different organic bodies; the following is its simplest expression:

The proportion of organic matter present in one part of the solution $= p$.
Specific gravity or density of the solution $= d$.
Length of the column of fluid employed $= l$.
Arc of rotation observed through red glass $= a$.
Molecular force of circular polarization $= m$.

$$m = \frac{a}{l\,p\,d}$$

The following is an example of the application of this formula:—MM. Biot and Persoz digested 400 parts of potato starch in a mixture of 160 parts of sulphuric acid and 1000 of water, and dissolved the sugar thus generated in water. The following data were obtained:

Proportions of saccharine matter in solution, $0{\cdot}210711 = p$.
Density of the solution, $1{\cdot}08391 = d$.
Length of column of fluid employed, $152^{mm} = l$.
Arc of rotation observed through red glass, $50^{\circ} = a$ ml

$= \dfrac{a}{pd} \dfrac{50}{{\cdot}210711 \times 1{\cdot}08391} = 218{\cdot}92 =$ the molecular force of circular polarization for a density of 1, and a thickness of 152; consequently $\dfrac{ml}{l} = \dfrac{218{\cdot}92}{152}$ $= 1{\cdot}44 =$ the rotating force of sugar of starch at an unity of density and thickness.

725. The most delicate test of the circular polarizing power of fluids where this happens to be too weak to produce any marked deviation of the planes of polarization, consists in examining the ray after it has traversed a column of fluid by means of a doubly refracting crystal of calc-spar (650). If, at any period of its revolutions, the two images should appear differently colored, it is certain that a rotatory power is exerted by the fluid under examination.

Elliptic Polarization.

726. If the difference of the paths of two systems of waves, instead of amounting to one-fourth of an undulation (607), is a fractional number, the movement which ensues will not be circular, but performed in ellipsis, producing elliptic polarization. This variety of polarized light is obtained by a series of reflections from metallic surfaces, differing in number according to the metal employed.

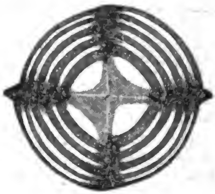
727.* Sir David Brewster discovered, in 1815, the property possessed by polished plates of gold and silver of dividing polarized rays by successive reflections into their complementary colors. Reflections from metallic surfaces but imperfectly polarize light; thus eight reflections from plates of steel, and about 36 from those of silver, are required to polarize the light of a wax-candle ten feet distant.*

* *Vide* Sir David Brewster, in Phil. Trans. 1830, and Prof. Powell in Phil. Trans. 1845, for an account of the phenomena of elliptic polarization.

If polarized light be reflected from metallic plates parallel or perpendicular to the plane of primitive polarization, no particular phenomena occur; when, however, the plane of reflection is inclined 45° to that of incidence, brilliant complementary colors are seen in the images, when the reflected light is analyzed by means of a doubly refracting crystal. These colors are peculiarly beautiful when the reflecting plate is composed of silver or gold.

728. Let a ray of plane-polarized light be reflected from a polished steel plate at an angle of 75°, and inclined 45° to the plane of reflection, the reflected light will be found to differ materially from the ray before reflection, as it does not vanish when viewed through a tourmaline or other analyzing eye-piece under the same circumstances as it did before reflection from the steel plate. It has, in fact, been converted into elliptically polarized light. The best test of this kind of light is the modification it produces in the rings of calc-spar (692), when viewed in a beam of it, instead of plane-polarized light; the transmitted light being analyzed as usual by a tourmaline or other eye piece. Under these circumstances the figure shown in the margin will be seen, which differs from that seen by ordinary polarized light, in the distortion of the black cross and dislocation of the rings, as if a film of selenite capable of producing a blue tint had been placed across the plate of calc-spar.

Fig. 343.



The conversion of the plane to the elliptically polarized ray may be effected by replacing the reflecting steel plate by a thin film of mica, previously heated red-hot, so as to split it into innumerable laminæ, and communicate to it a silvery lustre. This discovery we owe to Professor Forbes, of Edinburgh.

729. The angles at which a ray of plane-polarized light becomes elliptic by a single reflection from metallic surfaces, differs with different metallic substances. The following are some among a series given by Sir D. Brewster:

Metal	Angle for elliptic polarization.
Mercury	78° 27′
Speculum metal	76·0
Steel	75·0
Bismuth	7·45
Silver	73·0
Zinc	72 30
Jeweler's gold	70·45

Professor Powell has observed that in general the elliptically polarizing power of metals is greatly diminished by oxidation.

730. This variety of polarized light, when produced by any odd number of reflections from surfaces of steel, is restored to a state of plane polarization by an even number. Thus, a plane-polarized ray becomes elliptic with 1, 3, 5, 7, reflections from steel at 75°, and is restored to its primitive state by 2, 4, 6, 8, similar reflections.

731. A large number of crystals present different colors, according to the direction in which light is transmitted through them, constituting dichroism, a valuable sign of double refraction. An excellent example of this is met with in the chloride of palladium, which is deep red when viewed in the direction of its axis, and vivid green when examined transversely. Similar phenomena are observed in the iolite or dichroite, and many other natural and artificial substances. When such crystals are placed on the stage of the po-

lariscope, their colors will be found to vary with the inclination of the principal section (651) to the plane of polarization. The following list contains some of the results of Sir David Brewster's researches on this subject:

Colors of the Two Images, when Crystals possessing the Property of Dichroism are submitted to Polarized Light.

Names.	Plane of Axis situate in the plane of polarization.	Plane of Axis at right Angles to the Plane of Polarization.
	I. UNIAXIAL CRYSTALS.	
Sapphire	Yellowish green	Blue.
Emerald	Yellowish green	Bluish green.
Blue beryl	Bluish white	Blue.
Rock crystal	White	Faint brown.
Amethyst	Blue	Pink.
Tourmaline	Greenish white	Bluish green.
Idiocrase	Yellow	Green.
Mellite	Yellow	Bluish green.
Lilac apatite	Bluish	Reddish white.
	II. BIAXIAL CRYSTALS.	
Topaz, blue	White	Blue.
—— green	White	Green.
—— pink	Pink	White.
Caynite	White	Blue.
Dichroite	Blue	Yellowish white.
Epidote, olive-gr.	Brown	Sap-green.
—— whitish gr.	Pinkish white	Yellowish white.

NOTE.

In addition to the works on general optics and physics, and the papers diffused through the Philosophical Transactions, I would especially direct the student for further information on polarized light to the General View of the Undulatory Theory, by the Rev. Baden Powell, 1841, and to the Lectures on Polarized Light, by Dr. Pareira, in the second and third volumes of the Pharmaceutical Journal, and to a paper by Dr. Leeson in the Journal of the Chemical Society.

CHAPTER XXVII.

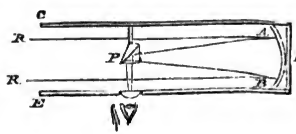
DESCRIPTION OF OPTICAL APPARATUS, AND OF THE EYE CONSIDERED AS AN OPTICAL INSTRUMENT.

Concave mirrors, 723. *Newton's telescope*, 733. *Gregorian and Cassegrainian telescopes*, 734. *Single microscopes*, 736. *Camera obscura*, 737. *Megascope*, 728. *Prismatic camera*, 739. *Solar microscope*, 740. *Magic lantern*, 741. *Camera lucida*, 742. *Soemmering's mirror*, 743. *Wollaston and Coddington lenses*, 744. *Compound microscopes*, 745. *Wollaston's doublet*, 746. *Achromatic microscope*, 747. *Reflecting microscopes*, 754. *Astronomic telescope*, 755. *Galileo's telescope*, 756. *Structure of the eye, considered as an optical instrument*, 758. *Action of the eye on light*, 759. *Structure of the eye in lower animals*, 760. *Seat of vision*, 761. *Causes of simple vision with two eyes*, 762—*of erect vision, with an inverted image*, 763. *Adaptation of the eye to different distances*, 764. *Duration of impressions on the retina*, 765. *Accidental colors*, 766. *Insensibility of the eye to certain colors*, 770.

732. OPTICAL instruments may be divided into the *catoptric*, including those depending upon reflection; the *dioptric*, or those acting by refraction; and those depending on the combination action of both effects; or *cata-dioptric* instruments. Of optical instruments depending on reflection, the various forms of mirrors already described constitute the most important. The common looking-glass, whose theoretical action has been already explained (568), is too well known to need description; and the convex mirror, so common an ornament in large rooms, is chiefly employed on account of the diminished images of objects which it produced, and thus the whole extent of a landscape becomes, as it were, compressed into the space of a few square inches. The concave mirror is a very important instrument, and, besides its application to science, it forms one of the most valuable resources of charlatans and jugglers, on account of the power it possesses of forming in the air an image of any object placed beyond its principal focus (557). Thus, if any object, as a dagger, strongly illuminated, be held towards a concave mirror, an image of it will be formed nearly in the conjugate focus, so vividly and perfectly painted in the air, that the person who holds the dagger can scarcely believe that the weapon which advances to meet him, is but a spectral image of the one with which he is armed.

733. The most important application of concave reflectors is to the construction of telescopes, in which the image of a distant object, as one of the celestial bodies, is formed in the principal focus of a concave mirror, and magnified by means of convex lenses (602). The simplest reflecting telescope is that constructed by Newton in 1666. This consists of a concave parabolic (604) metallic reflector AB, fixed at the end of a tube CDE. A small plane mirror (569), inclined at 45°, or, still better, a rectangular prism P, is fixed in the tube, between the speculum AB and the image formed in its focus. The image thus becomes reflected towards the opening in the side of the tube, where it is viewed through a convex lens for the purpose

Fig. 344.



of magnifying it.* The advantage of a prism over a plane mirror, for the purpose of reflecting the image of the distant object towards F, is sufficiently obvious; for, by *internal* reflection (585) from the back of the prism, nearly all the rays are reflected to the eye; whereas, if a plane metallic speculum were substituted, about forty-five out of every hundred rays would be lost (567), from the undulations producing them being checked on reaching the surface of the metal. For the purpose of preventing spherical aberration (603) from interfering with the distinctness of the images, Newton placed, between the eye and the convex lens, a plate of metal, pierced with a small hole, through which he viewed the object.

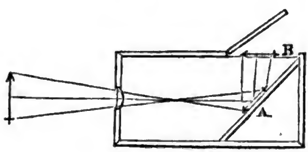
734. The Gregorian reflecting telescope was invented in 1660, by Dr. Gregory, but not actually constructed until some years subsequent to Newton's. In this instrument, the inconvenience of taking a lateral view is avoided. It consists of a concave speculum fixed in a tube, but pierced in the centre with a hole, through which, by means of a lens, or a combination of lenses, the image of the object is viewed. The rays forming the image of the object in Dr. Gregory's telescope are incident on a small concave mirror, and form a fresh image, which is viewed through the aperture in the centre of the large speculum. The observer, in using this telescope, is placed in a line with the object; whilst, in Newton's, he is at right angles to it.

735. When a convex mirror is substituted for the small concave one in Dr. Gregory's instrument, we have the Cassegrainian telescope. In this, the image is more distinct than in any other construction, as but one image is formed; and as one speculum is concave and the other convex, they have a tendency to correct each other's spherical aberration.

736. The number of optical instruments in which light is refracted is almost infinite, including all varieties of simple and compound microscopes, refracting telescopes, &c. The single microscope consists only of a lens, with a focal length varying according to the amplifying power required (603). Small spheres of glass, made by fusing a filament of glass into globules, are frequently employed; their action upon light, and magnifying power, will be readily understood from the remarks already made (591).

737. If, instead of permitting the image to be painted on the retina of the eye, it be received on a screen, we have a camera obscura, or solar microscope, according to the arrangement employed. If a convex lens be fixed in a hole made in one end of a box, a little longer than the focal length of the former, painted with some black pigment, for the purpose of absorbing all extraneous light, the image of a landscape, to which the lens is presented, will be beautifully and vividly painted, in an inverted direction, on a sheet of paper fixed at the end of the box opposite to the lens. Sometimes, instead of receiving the image on a sheet of paper, it is reflected by a plane mirror, A, placed at an angle of 45° towards the upper part of the box, a sheet of white paper, or piece of ground glass, B, being there placed to receive it.

Fig. 345.



In this mode the image appears erect, and inverted only as regards the right or left portions, and is usually preferred for the purpose of sketching distant views. As the lateral portions of the picture are indistinct from spherical aberration, a meniscus lens is pre-

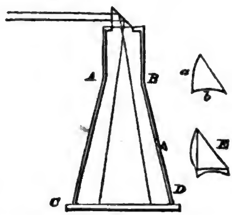
* Newton, Optice, Lib. i. prop. 8, prob. 2.

ferable to any other form of convex glass, for the purpose of reducing this serious source of incorrectness to a minimum.

738. If any small object, strongly illuminated, be placed outside of a camera obscura, and a little beyond the principal focus of the lens (594), an image of the object will be beautifully depicted on the paper screen at the end of the box. An instrument thus arranged is termed a Megascope.

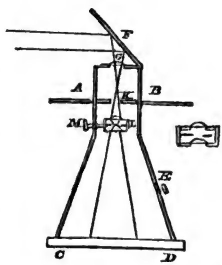
739. The best form of camera obscura is that in which internal (585) instead of specular reflection is employed, to prevent the loss of light attendant on the latter. The box is then made of a pyramidal form ABCD, and a rectangular prism, having one of its faces *a* convex, and another *b* concave, is placed over an aperture in the top of the box. The rays from a distant object will be made to converge after impinging on the convex surface *a*, and being reflected in the interior of the prism, will pass into the box, and paint the image on a sheet of paper placed at the bottom CD to receive it. The picture thus obtained is extremely vivid, from the perfect reflection of rays from the back of the prism, and from the spherical aberration being to a great extent counteracted by the concave face of the prism. As these meniscus prisms are difficult to procure, they may be very advantageously replaced by a rectangular prism having a plano-convex and a plano-concave lens, of proper focal length, cemented by Canada balsam on two of its faces, as shown at E.

Fig. 346.



740. When a vivid beam of light, before being made to diverge by refraction through a lens, passes through a small transparent body placed before it, an enlarged image of the object will be painted on a screen placed at a proper distance behind the lens. This is the principle of the solar microscope. The simplest form of this instrument consists of a pyramidal box ABCD, furnished with a door at E, like a camera obscura (739). The solar rays falling directly, or reflected by a common looking-glass on a plane mirror F, are reflected to the plano-convex lens G, where they undergo refraction, and fall on an object placed at K, nearly in the principal focus (593) of G. The light then passes through two plano-convex lenses, each of about half an inch focal length, at L, movable by means of rackwork at M, forming a widely diverging beam, paints an enormously magnified image of the object a the bottom of the box, where it may be viewed through the door E. To prevent, as much as possible, spherical aberration (603), a diaphragm of metal, pierced with a small hole, should be placed between the two lenses at L.

Fig. 347.



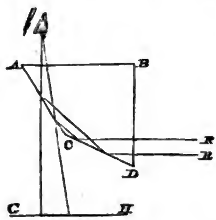
If the mirror F be removed, and the direct light of an Argand lamp be incident on G, we have the lucernal; and if the light of mixed oxygen and hydrogen gases be employed, we have the oxy-hydrogen microscope.

741. The magic lantern differs scarcely at all in principle from the three last described instruments. The light of a lamp, placed in a tin or wooden box, is reflected by means of a concave mirror, or condensed by a lens, on figures painted in vivid transparent colors on slides of glass; the light then

is converted into a large diverging beam by refraction through two convex lenses placed near the objects, and capable, by a sliding tube, of being adjusted to such a distance as to cause the image, when received on a white opaque screen, to be as vivid and distinct as possible; the magic-lantern being nothing more than a lucernal microscope of low magnifying power. If the screen on which the object is painted be transparent, and the spectator be placed behind it, the image will, in a dark room, appear to be painted spectre-like in the air, constituting the well-known phantasmagoria.

742. A very valuable instrument, termed the camera lucida, for taking drawings of landscapes, &c., depending upon internal reflection, was contrived by Dr. Wollaston, in 1807. This consists of a quadrangular prism. the angle B being 90°, D 67·5°, and C 135°. Rays RR, evolved from any distant object, will, after incidence on CD, be reflected in the interior of the glass to CA, and thence to the eye placed above the angle A. And as all objects appear to be placed in the direction of the rays which eventually reach the eye, the image will appear to be painted on a screen or sheet of paper at GH; and if a perforated piece of metal be placed on AB, so that one-half only of the aperture be over the angle A, the image and paper will both be visible to the eye placed over the aperture; and a sketch of the object may thus be taken with extreme accuracy, by simply copying the outlines of the figure seen depicted on GH.

Fig. 348.



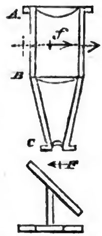
743. A very excellent instrument, advantageously replacing the camera lucida, especially in making microscopic drawings, is the mirror of Soemmering. This consists of a small round speculum of steel, about one fourth of an inch in diameter. This being fixed before the eye-glass of a microscope at an angle of 45° with the axis of the instrument, a person looking into it (the body of the microscope being arranged horizontally) will see the image of any object placed on the stage reflected on the table. At the same time, from the small size of the mirror, the surrounding objects are visible, and thus, with a little management, the outlines of the image can be easily traced with a pencil.

744. When simple lenses are used for single microscopes, it is important to diminish spherical aberration as much as possible, by permitting only those rays which pass near the centre of the glass to reach the eye. This may, to a great extent, be effected by Dr. Wollaston's method, by placing between two plano-convex lenses, a piece of metal perforated in the centre. A better mode of obtaining the same effect is by grinding away the equatorial portions of a spherical lens, as in the well-known Coddington lens, which is the most perfect of any hitherto constructed.

745. Microscopes composed of two, or several lenses, are termed compound, and are preferred to the simple instrument, from their larger field of view, and their not, when properly constructed, fatiguing the eye so much as those composed of but one lens of very short focal distance. In these microscopes, a magnified image of an object is formed, by allowing the rays passing through, or reflected from it, to be refracted through a lens of short focal distance; the image thus produced is viewed by a second lens of much lower magnifying power. Thus, in the compound microscope, we examine the magnified image

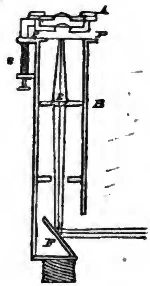
of the object, whilst in the single instrument the magnified object itself is seen; and hence the former requires excessive care in their construction, to ensure an accurate and perfect image. If ABC be a tube of brass, blackened inside to absorb superfluous light, and provided with a small lens at C, an object placed in its focus at F strongly illuminated, by light reflected from a mirror placed below it, will have an image of it formed in the focus of the eye-glass A at *f*, and may be viewed through A, by which the diverging rays are made to enter the eye in a parallel direction. For the purpose of increasing the field of view, a third lens B is often introduced; this causes the diverging rays going to form the image to diverge still more, and a larger image, as shown by the dotted lines, is formed at *f*. The distance at which the object-glass C is from the eye-glass A must always exceed the sums of their focal lengths.

Fig. 349.



746. The most valuable microscope for a certain class of objects, on account of the great distinctness of the image, is the doublet of Dr. Wollaston. This consists of two small plano-convex lenses, whose focal lengths are as 1 to 3 fixed in the brass cups A, the least convex lens being nearest the eye. The brass tube B is about six inches long, furnished below with a plane mirror at F; a circular aperture is made in a piece of brass placed above it, through which the light reflected from F passes to undergo refraction through the convex lens E, so as to form a distinct circular image of the aperture at the distance of about 0·8 inch from E. The object to be examined is placed on a slip of glass on PP, and the lenses in A are adjusted by means of a screw at S. By this instrument, the most delicate markings and finest striæ on very minute objects, are clearly and distinctly seen.

Fig. 350.



In all ordinary microscopes, the centre and edges of the magnified image are never equally distinct, from the spherical aberration of the lenses (603). To remedy this, diaphragms perforated in the centre are placed in the body of the microscope, to exclude those rays which are refracted from the edges of the lenses. Menisci (590), or the compound lenses contrived by Sir John Herschel, may be used for eye-glasses, so as to prevent this aberration from interfering with the distinctness of the image.

747 We have seen that if a doubly convex lens be cemented by means of Canada balsam to a plano-concave lens (628), so that a convex surface of the former will accurately fit into the concavity of the latter, it is obvious that a compound plano-convex lens will result, whose magnifying power will be equal to that of the doubly convex lens, *minus* the diminishing power of the plano-concave used in its construction. In such a compound lens, no advantage would be gained over a simple plano-convex lens of the same curvature, so long as the plano-concave and doubly convex glasses were composed of media possessing the same dispersive powers (519). We have already learnt, that different varieties of glass possess very different intensities, with regard to the resolution of light into colored rays; if, therefore, the plano-concave lens be of flint glass and the doubly convex of crown-glass, a compound lens will result, in which the magnifying power will be less than the doubly convex lens by itself, but which will possess the superior advantage of giving an image nearly free from marginal fringes of the prismatic colors, providing the curvatures of the constituent lens have been properly adjusted.

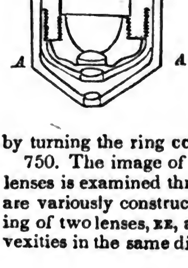
A compound achromatic lens thus constructed forms an excellent object-glass for a compound microscope, giving a nearly colorless image of the object, which will bear a higher magnifying power in the eye-glass than any object formed by an ordinary lens of equal focal length.

748. As it is a matter of great practical difficulty to balance the chromatic and spherical (507) aberrations perfectly in a single pair of lenses, immense advantage is gained by the combination of two or three pairs, in which the aberrations of each are mutually balanced. Object glasses constructed on this principle have, in the experienced hands of Messrs. Hugh Powell, Andrew Ross, and Smith, been lately brought to an amount of perfection which could scarcely have been anticipated.

Among other advantages presented by an achromatic object-glass, is the fine illuminations of the image, arising from the larger pencil of rays which can be admitted into the body of the instrument. This may be readily understood by a reference to what has been already stated with regard to the use of diaphragms or stops, in the structure of optical instruments. These are perforated pieces of metal so placed as to cut off the more external rays of a pencil passing through a lens, and thus permitting only the central rays to reach the eye; and in this manner many of the aberrations of a lens are practically reduced to a minimum, at the expense, of course, of a vast loss of light. The achromatic construction, by allowing the transmission of a larger pencil of rays, enables us to use high magnifying powers with a perfection of illumination previously unknown.

749. So delicately are the aberrations of a well made achromatic object-glass balanced, that the simple examination of an object covered with a piece of glass or mica, is sufficient to interfere with the perfection of the image. It must be borne in mind, that the constituent lenses of an object-glass are arranged for the examination of naked or uncovered objects, and as we have seen that the interposition of a parallel refracting medium affects the angles of divergence and conveyance of transmitted rays (492), it is obvious that lenses, if adjusted for the examination of naked objects, will require some correction, if a plate, however thin, of a refracting medium be interposed. This effect is of course only practically perceptible when object-glasses of high power are employed; and we are indebted to the ingenuity of Mr. Andrew Ross for a knowledge of the mode of correcting it. The object-glasses constructed with this improvement are connected with a piece of mechanism shown in the marginal figure. The two posterior achromatic lenses are fixed in the end of the tube B. Upon this slides a cylinder AA, carrying at the end the third or anterior lens, which by turning the screwed ring CC, may be approximated to, or separated from, the other two lenses. The proper distance for the adjustment of these lenses for uncovered objects is known by a line marked on the tube A, coinciding with one on the tube B; and, when objects are examined which are covered with glass or immersed in a fluid, the distance of the third lens from the other two is altered by turning the ring CC, until a perfect definition of the object is obtained.

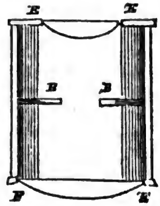
Fig. 351.



750. The image of an object thus formed by the achromatic combination of lenses is examined through eye pieces of different magnifying powers. These are variously constructed, but the most approved are the Huyghenian, consisting of two lenses, EE, and FF, (fig. 352,) each being plano-convex with their convexities in the same direction. EE is termed the eye-glass, and FF the field-glass,

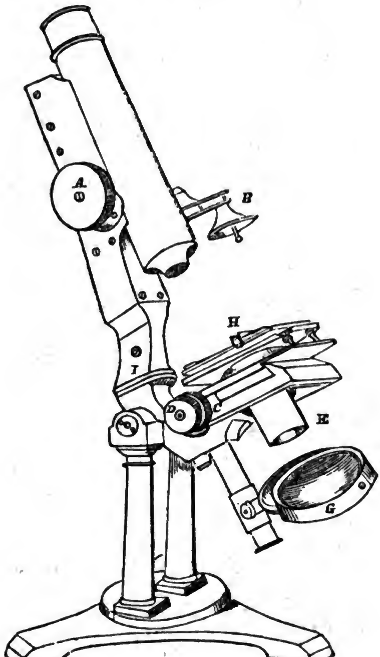
for reasons already pointed out. A perforated stop or diaphragm is placed at B B, to cut off the extreme rays that might interfere with the perfection of the image.

Fig. 352.



751. All that is essential to the construction of a perfect microscope is, then, a good achromatic combination of lenses to form an image of an object, and a well-made eye-piece to magnify this image. The distance at which the object-glass and eye-piece are placed, must always exceed the sum of their respective focal lengths. It is obvious that the magnifying power of a microscope can be increased in two modes, by increasing the magnifying power of the object-glass, and thus form a larger image of the object, or by examining this image with a deeper eye-glass (i. e. one of higher magnifying power). The first mode is undoubtedly the most accurate, as by the second we magnify any errors which may exist in the image formed by the object-glass, as well as the image itself. Still, with good and trustworthy object-glasses, we may often conveniently examine the image with different eye-pieces, and thus avoid the necessity of altering the position of the object or removing the object-glass. Accordingly, some of

Fig. 353.



the continental microscopes, as those made by Oberhäuser, are provided with a series of six eye-pieces of different magnifying powers. English microscopes have, however, seldom more than two or three.

752. The mechanical arrangements of a microscope are scarcely of less importance than the perfection of lenses. As a general rule, that form of support which combines the greatest firmness with the most facility for the necessary adjustment, is to be preferred. The stage should always be a fixture, and the adjustments effected by moving the body of the instrument. Many forms of support for the optical part of the microscope have been constructed by Prichard, Ross, Smith, and Powell, in this country, and each has, probably, its peculiar recommendations. I consider, however, that for a really working instrument, capable of being applied to any purpose for which a microscope can be employed, the one constructed by Mr. Powell, and figured in the preceding page, is probably the best.

The whole instrument is supported on a double pillar resting on a firm triangular foot. The cylinder, in the lower end of which is screwed the object-glass, with its fine adjustment B, moves on a firm support I by means of rollers, so that by turning the milled head A, it may be placed within any required distance of the stage. The latter consists of a lower portion C, fixed to the support of the instrument, and provided internally with a pinion and screw, so that the upper plate H of the stage can be moved in any direction, by turning the heads of the screw D. The upper portion of the stage is provided at H with a spring slide, to grasp the plate of glass holding the object under examination, and has, moreover, a rotatory motion by which the latter may be placed in any required position.

The object, if viewed by transmitted light, is illuminated by means of a mirror G, the light being, when required, condensed by means of an achromatic lens fixed at the end of the tube E. So that the object is illuminated by colorless light, as well as being examined by lenses, which if properly adjusted, do not generate false colors, and thus the magnified image produced is as perfect as possible.

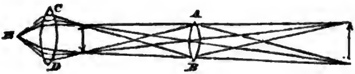
753. The linear magnifying power of these instruments is of course limited only by the focal length and accurate adjustment of the object-glass with regard to chromatic and spherical aberration. In the practical application of the microscope it should, however, never be forgotten, that *the lowest power with which an object can be distinctly defined and examined is always to be preferred.* The following table contains the different magnifying powers obtained with different eye-pieces and object-glasses, in Mr. Powell's microscope.

Focal length of object-glass, in inches . .	$\frac{1}{16}$	$\frac{1}{8}$	$\frac{1}{4}$	$\frac{1}{2}$	1	2
First eye-piece	700	330	170	75	40	20
Second ditto	1400	660	150	80	80	40
Third ditto	2500	1200	600	250	140	70

754. Reflecting microscopes, on the same principal as Newton's telescope (733), have been constructed by Professor Amici of Modena, and others. In these instruments, the object is placed in one focus of a small and finely polished ellipsoidal speculum, and its image formed in the other focus is examined by means of a magnifying eye-piece, consisting of one or more lenses.

755. The refracting telescope was invented in the thirteenth century, although the discovery appears to have been nearly lost until the sixteenth. The simplest telescope is that employed for astronomical purposes, and consists of a convex lens of long focal distance fixed at one end of a tube, and exposed to the object, the image of which, when formed in the focus of the lens, is examined by a second convex lens, or eye-glass, of shorter focus. These lenses should, for distant objects, be placed at a distance from each other, corresponding to the sum of their focal lengths. In the following figure, AB is the object-glass, and CD, which must always be of shorter focus, the eye-glass, and

Fig. 354.



placed, if the focus of the former were eight, and that of the latter, two inches, at a mutual distance of ten inches. To accommodate this instrument to objects at different distances, the eye-glass is usually fixed in a tube which slides within that containing the object-glass, and thus permits a ready adjustment of the instruments. In this telescope, the object appears inverted from the intersection of the rays by refraction, and hence its use is extremely limited. An erect image may be obtained by adding two other convex lenses behind CD, and of the same focal length, but a loss of light is necessarily produced by their use. Spherical aberration may be prevented as much as possible, by the same means as in the case of compound microscopes.

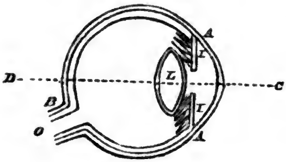
The magnifying power of these telescopes is found by dividing the focal length of the object-glass by that of the eye-glass.

756. If a concave eye-glass be substituted for the lens CD in the last described instrument, we have the Galilæan telescope, which exhibits objects in an erect position and with very great clearness. The lenses in this instrument are placed at a mutual distance, equal to the *difference* of their focal lengths, and hence telescopes on this construction are much shorter than in those in which both lenses are convex. The magnifying power of this telescope is found by the same rule as that already given for the astronomical telescope. From the smallness of its field it is chiefly limited to the construction of opera-glasses.

757. Having reviewed the theoretical construction of some of the most important instruments used for optical investigations, the student will be enabled, from the preceding observations, to understand the mode in which the eye acts upon light so as to prepare it for communicating to the sensorium the images of objects by which we are surrounded, and thus develop the sense of sight. The following observations, it must be borne in mind, apply only to the eye, considered as an optical instrument of the most perfect kind, and unconnected with the physiological relations of the subject, except such as are essential to a knowledge of the physical action of the organ of vision. The following figure represents a transverse section of the left eye (human), made by passing a plane through it, parallel to the opening of the eyelids. The form of the eye is nearly spherical, four-fifths of its circumference ABA being nearly circular, the remaining fifth AA constituting the transparent portion, being more convex, and forming a curve of a lesser sphere. After removing the muscles attached to the eyeball, the most external coat becomes visible. This is a tough, pearly, opaque membrane, termed the *sclerotic* coat, extending from the entrance of the optic nerve O, on the nasal side of the optic axis CD to AA,

where it terminates in a circular opening, furnished at its margin with a grooved edge, into which fits the *transparent cornea*, in the same manner as a watch-glass fits into the grooved circular piece of metal made to receive it. The cornea is as transparent as glass, and is about one-third of a line in thickness. A delicate mucous membrane, termed the *conjunctiva*, is expanded over the cornea and sclerotic, and thence reflected to the inner surface of the eyelids. Lining the sclerotic coat is the *choroid* membrane extending from o, to the anterior part of the eye contiguous to the margin of the cornea, where it terminates in the *ciliary ligament*, constituting a bond of union between the choroid, sclerotic, and iris. The choroid being here thrown into a number of puckered folds, the interior surfaces of which, as well as of the whole extent of the membrane, are covered with a black pigment. The optic nerve o enters the eye on the nasal side of the optic axis, and expands into a third coat termed the *retina*, which passes towards the anterior part of the eye, and terminates in a well defined edge. The retina is the membrane upon which the images formed by the refracting structures of the eye become painted: it is prevented becoming stained by the black pigment with which the choroid is imbued, by a delicate intervening transparent double membrane, termed Jacob's membrane.

Fig. 355.



A delicate fibrous irritable structure, named from its various colors the *iris*, is suspended vertically from the ciliary ligament having in the centre an aperture, termed the pupil, which is capable of becoming enlarged or diminished involuntarily, under the stimulus of light. The iris is shown in the section at II; the space between it and the cornea is termed the anterior chamber of the eye, and is filled with a fluid known as the aqueous humor. Behind the iris is suspended in a capsule a transparent double convex lens L, whose posterior is greater than its anterior convexity: this is termed the crystaline lens. The remaining portion of the ball of the eye is filled up by a refracting structure termed the vitreous humor, in the anterior portions of which the lens L is imbedded: this is made up of a fluid contained in the convoluted folds of a transparent hyaloid membrane. The total length of the eye, along the optic axis CD, is about 0·91 of an inch.

758. From the investigations of Sir David Brewster, the following are the refractive indices (581) of the different refracting structures of the eye, when light is incident upon them from air, or from each other:

Ref. Index for light, passing from air into the aqueous humor	1·3366
Ref. Index for light, passing from air into the vitreous humor	1·3394
Mean ref. Index for light, passing from air into the crystaline lens	1·3839
Mean ref. Index for light, passing from the aqueous humor to the crystaline lens	1·0353
Mean ref. Index for light, passing from the vitreous humor to the crystaline lens	1·0332

Rays of light, on impinging upon the eye, are refracted through the transparent cornea, those incident on the sclerotic being reflected. The cornea may be regarded as constituting the anterior surface of a meniscus lens, of which the posterior surface is formed by the capsule of the crystaline lens,

the aqueous humor forming the refracting medium of this fluid refractor. The rays of light which thus tend to be refracted to a focus, pass through the pupillary opening of the iris, those passing too near the margin of the lens formed by the anterior chamber, being reflected or absorbed: the iris, answering the purpose of the perforated diaphragms (746) in microscopes and telescopes, and being capable of varying its aperture, possesses advantages altogether unattainable in metallic diaphragms. The pencil of rays having passed through the fluid meniscus, impinges on the crystaline lens, and becomes considerably refracted; this refraction being increased by the action of the vitreous humor, the last medium into which it passes; and finally paints upon the retina an inverted image of the object, from which the luminous undulation producing the rays were propagated. All rays which are reflected in the interior of the eye, or pass too obliquely for distinct vision, have their undulations checked by the black pigment with which the choroid coat and its folds are imbued.

759. The refracting structures of the eye thus act upon light, and produce an image of any object upon the retina in the same manner as a convex lens does (599), with the advantage of increased clearness of the picture from the absence of spherical aberration (603), produced by the curved form of the retina, and by the structure of the crystaline lens; the refractive power of its centre being greater than that of its surface, in the ratio of 1·3990 to 1·3767. This diminution of aberration is also assisted by the pupil, which acts in the same manner in preventing spherical aberration, by being placed between the fluid meniscus and the crystaline convex lens, as does the perforated diaphragm in Dr. Wollaston's, or the excavated sines in Coddington's lenses (744). Chromatic aberration (628) is, doubtless, to a certain extent, compensated in the eye, by the different dispersive powers (616) of its several structures; although this organ is by no means perfectly achromatic, as may be shown by the spectral colors observed fringing minute bodies held near the eye. Nor is this achromatic state necessary for the perfection of vision, as the deviation of the different colored rays is too slight to produce any degree of indistinctness.

760. The eye in all warm-blooded animals is formed upon the type of that of man, with the occasional addition of supplementary portions, better fitting the organ for the performance of vision in the particular animal. In fishes, residing in a medium of nearly the same refractive index as the aqueous humor, the latter fluid becomes useless, and is replaced by a viscid secretion of greater refractive power. The crystaline lens is, in these animals, nearly spherical, and placed close behind the cornea, and the iris which is close to the latter is undilatable. In insects the eye is very simple, consisting of a lenticular cornea, placed in front of a nervous expansion.

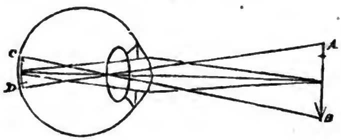
761. Although it is demonstrable that images of external objects are formed upon the retina, it has been doubted by some whether the latter membrane is the seat of vision, as in certain species of cuttle-fish an opaque membrane is found between the vitreous humor and retina. The choroid coat and vitreous humor have each been supposed to be the true seat of vision. It is a curious fact, that the point where the optic nerve enters the eye is absolutely incapable of distinct vision, and if the image of any object falls upon it, it ceases to be visible. This may be shown by placing three wafers on the table, about two inches distant from each other, and having closed one eye, look at the outside wafer on the same side as the closed eye: at the distance of about eight or ten inches from it, the two outer wafers will be distinctly seen, whilst the middle one will be quite invisible. It appears from this experiment, that if vision really depends upon some vibratory movement excited in the membrane, on which the images of objects become depicted, the reason why the base of the optic nerve is insensible is, that it is too dense to

assume those movements which its expansion, the retina, have readily communicated to it.

762. When an object is viewed with both eyes in a healthy person, it appears single, whilst it is obvious that a distinct image is painted upon each retina. This is readily explained by the fact, that the two images lying exactly in the direction of the optic axis, overlap each other, and virtually produce but one image. If one eye be pushed out of the optic axis, these images are separated, and then, as in the case of squinting persons, the object appears double.

763. Many ingenious arguments have been used to explain why objects appear erect, whilst their images painted upon the retina are inverted, although a little reflection on this circumstance renders it probable that such must necessarily occur, from the law, that all objects appear to be placed in the direction pursued by the rays which eventually reach the eye. If AB be an object from which the rays following the direction of the lines shown in the figure pass into the eye, they become refracted towards the retina, and paint upon it the image CD. Then if the retina be supposed to be the seat of

Fig. 356.



vision, the impression communicated by it to the sensorium is that of an erect object; for the part D of the image will appear to be placed in the direction of the rays DA, and the upper part C will appear to correspond with the lower part B of the object, which will appear to be situate in the direction of the rays CB. Consequently, although the image painted upon the retina is really inverted, it conveys to the mind the sensation of an erect object.

764. The really most marvelous subject connected with the eye, as an optical instrument, is its power of adapting itself to various distances; for it is well known, that in viewing objects through a telescope, the distance of lenses from each other in the latter, requires to be altered by drawing out or thrusting in the slides of the telescope, whereas the eye appears intuitively to accommodate itself to the various distances at which objects happen to be placed. Whether this is effected by an alteration in the form of the entire eye by the action of its muscles, or of the crystaline lens only, appears to be a matter of doubt; the alteration in the pupillary opening could only very slightly assist in obtaining this end, unless this is accompanied, as is very probable, by a partial displacement of the crystaline lens.

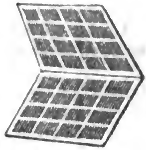
765. The impression of an object upon the retina lasts for an appreciable time after the former is withdrawn, and hence the eye may be rapidly closed and opened without losing sight of an object. If a burning coal or red-hot bar be made to revolve so rapidly, that the whole revolution may be completed in about 7‴, an entire luminous circle is produced. The impression thus vividly excited upon the retina appears to continue about one-seventh part of a second of time.

766. It has been shown that the undulations of white light may be resolved into two sets, producing upon the retina different colors complementary to each other, or which, when striking the eye together, will produce the sensa-

tion of white light. When any person gazes upon a *red* wafer, strongly illuminated, for some seconds, and then suddenly turns the eye to a white surface near it, a spectral image of the wafer, but of a *green* color, will become visible. If the wafer be yellow, and placed on a black surface, the spectral image will be deep violet when viewed on a white ground; in the same manner a white wafer is attended by its black spectral figure. Thus wafers, or other colored objects, produce spectra of colors complementary to their own. The complementary tints thus produced are termed accidental colors, and may be found by reference to Newton's experiments on thin plates, the reflected and transmitted tints being complementary to each other (614).

767. The most complete mode of demonstrating this color is the following, for which I am indebted to Mr. Cowper of King's College. Cut in a piece of card board a series of holes, so that when folded together they will exactly correspond; the whole resembling open lattice-work. Provide some sheets of thin tissue-paper of various colors, selecting those presenting strongly defined tints. Place one of these between the folds of the card-board and hold it up to a vivid light, keeping the eye fixed on the lattice-work whilst the light penetrates the colored paper. In a few seconds the white color of the paste-board will vanish and be replaced by a strongly-marked tint complementary to that of the paper placed in it. Thus with yellow paper the frame-work will appear violet, with blue it will be orange, and with red it will be green. The illusion is so complete that it always excites surprise in those who see it for the first time.

Fig. 357.



768. These accidental tints have been explained by Sir David Brewster, in the following manner:—The eye being strongly excited by gazing on a colored body, as a red wafer, becomes partially paralyzed to the action of undulations producing that tint; and on then allowing white light to impinge upon the eye, those undulations, which move with such a velocity as to produce upon an unexcited eye the sensation of a color corresponding to that of the wafer, are without action on the temporarily paralyzed organ; and the remaining set of undulations are alone active, producing on the retina the sensation of a tint complementary to that of the wafer.

769. A remarkable case of resolution of white light into its complementary tints, by unequally exciting the eyes with white light, has been described by Mr. Smith.* If we hold a slender slip of white paper vertically about a foot from the eyes, fixing both the latter upon an object at some distance beyond it, so as to see the paper double, and allow the light of a candle to act vividly on the right eye, without affecting the left, the left-hand image of the strip of paper will appear to be bright green, whilst the other will exhibit the complementary color, or red. If the direction of the source of light be changed, the position of the complementary tints will become reversed.

770. Individuals are not unfrequently met with, whose eyes are as insensible to certain tints, as the ears of some are to particular sounds. Several cases of this kind have been described, in which the following colors have been confounded by the persons affected with this curious defect of the visual organs:†

Bright green, with grayish-brown and flesh-red,
Rose red, with green and gray,
Scarlet, with dark green and hair-brown,
Sky-blue, with grayish-blue and lilac-gray,

* Edin. Journ. Science, iii. p. 1.
† Seebeck in Poggendorff, Annalen, xlii. 177.

Brownish-yellow, with yellowish-brown and grass-green,
Brick-red and rust-brown, with deep olive-green,
Dark-violet, with deep blue.

This remarkable state occasionally occurs in disease, and disappears on the patient's recovery. I had once a patient affected with cerebral disease under my care, in whom vision was previously perfect, but during the attack she confounded several tints with each other. The colors mistaken for each other in this instance were in general the complementary ones; red being mistaken for green, and orange being confounded with blue. Of the physical cause of this remarkable state, however, nothing is known.

NOTE.

In the elaborate Monograph on Light in the Cyclopædia Metropolitana, by Sir John Herschel, the student will find a most valuable source of reference for everything connected with physical optics. The Essay on Optics by Sir David Brewster, in Lardner's Cyclopædia, will prove a most excellent guide for the less advanced student.

For further information on the subjects treated of in the last seven chapters, in addition to the general treatises on physics before referred to, the reader should consult the Treatise on Optics by Sir Isaac Newton, the Essay on Optics by the late Dr. Wood, of Cambridge, Dr. Young's Elements on Natural Philosophy, and Müller's Physics, section v. In the researches of Sir David Brewster on polarized light, diffused through a series of papers in the Transactions of the Royal Societies of London and Edinburgh, will be found every information on that interesting department of physics.

CHAPTER XXVIII.

THERMOTICS.

COMBINED HEAT.

Theories of heat, 771. *Proximate causes of heat*, 772. *Heat and cold*, 773. *Expansion*, 774; *of fluids*, 775. *Water an exception*, 776. *Thermometers, air*, 778; *Leslie's*, 779; *Mercurial*, 780; *graduation of*, 781; *Formula for*, 782. *Table of centigrade degrees*, 783. *Breguet's metallic thermometer*, 784. *Pyrometers*, 785. *Varying expansion of fluids*, 787. *Conduction of heat*, 788. *Laws of heating and cooling*, 789. *Table of solid conductors*, 790. *Bad conducting power of fluids*, 791; *of gases*, 792; *of articles of clothing*, 793. *Convection of heat*, 795; *capacity for*, 798. *Specific heat*, 799; *Ratio of, to atomic weight*, 800; *of gases*, 801. *Latent heat*, 802. *Abstraction of heat by solution*, 806; *evolution of by solidification*, 807. *Latent heat of steam*, 808. *Expansion of fluids in vaporation*, 809. *Congelation of bodies*, 810; *ebullition of*, 811. *Spherical state of fluids by heat*, 812. *Freezing of water in red-hot vessels*, 814. *Production of ice by evaporation*, 815. *Ratio of atmospheric pressure to ebullition*, 817. *Cryophorus*, 818. *Atmospheric vapor*, 819; *elasticity of*, 820. *Hygrometers*, 821. *Dew-point*, 822. *Daniell's hygrometer*, 823. *Wet-bulb hygrometer*, 824. *Chemical action of heat*, 825.

771. The same difference of opinion has existed among philosophers with regard to the distinct cause of heat from light. Some have contended that the evolution of heat, as of the sun and other sources, depended upon the emission of infinitely minute particles of matter, to which the general term *caloric* was applied. Others again have applied the undulatory hypothesis to the explanation of the phenomena of heat as of light (551), and have supposed that these are merely the results of the undulations of an imponderable ether equally diffused with that, whose tremulous motion produces light, if it be not identical with it. Researches on the subject render it, at least, probable that heat and light depend upon the undulatory movements of the same ether, the former being the result of such motion when made with too little rapidity to produce the latter.

772. The chief proximate cause of heat is the sun, whose rays convey to us this important agent in common with light. There are, however, other exciting causes chiefly of a mechanical and chemical character, to which it is necessary to allude.

A. Friction.—Produced whenever two bodies are rubbed together. Thus, when two pieces of ice are rubbed together, sufficient heat is generated to melt them. Among uncivilized nations, heat is produced by the natives by the friction of pieces of wood against each other. Count Rumford found that in the operation of boring a brass cannon, 7½ inches in diameter, the borer making thirty-two revolutions in a minute, with a pressure of 10,000 pounds, sufficient heat was generated to boil eighteen pounds of water, in which it was immersed, in 2½ hours.

B. Percussion.—This is an active mechanical source of heat, and appears

to depend upon its producing a diminution of bulk in the body struck, for, as a general rule, whenever bodies are diminished in bulk, heat is evolved. This is well illustrated in the coining press. Berthollet submitted a piece of copper to the stroke of a press, and found that the greatest evolution of heat occurred at the first blow, and diminished with each succeeding one.

With the first stroke	17·3° F.	of heat	were evolved.	
——— second ——	7·5°	ditto.	ditto.	
——— third ——	1·9°	ditto.	ditto.	

C. Chemical action.—An active source of heat, including all cases in which the action of heterogeneous particles are exerted on each other, as in combustion, &c.

D. Electrical action.—Examples of this mode of evolving heat have been already given (427); it appears to be connected with the resistance afforded by conduction to electric induction taking place through them.

E. Vital action.—All beings possessing life have the property of evolving heat, and generally of maintaining a temperature above that of the medium in which they live. In the case of animals, at least, it is highly probable that the evolution of heat depends upon a slow combustion going on in the organism, carbon and hydrogen being slowly converted into carbonic acid and water, not only in the lungs, but in every portion of the capillary system (540). A theory long ago advanced, and to which notice has been more recently drawn by the ingenious arguments of Prof. Liebig.

773. When a body has acquired the power of communicating the sensation of heat to others it is said to be *hot*, and when, on the contrary, it takes heat from the hand when brought near it, the body is said to be *cold*. Not the slightest difference of weight takes place in bodies by the abstraction or communication of this power of communicating the sensation of heat; a mass of matter so cold as to freeze a little water when placed upon it, weighing the same as when of the temperature of boiling water; the bulk of the body alone undergoing a change.

774. When the temperature of bodies is increased, they, with few exceptions, increase in bulk. This increase arises from the repulsive power of heat, for when this agent is excited in bodies their molecules exert a power of mutual repulsion, causing, first, their increase in bulk; next, the alteration of the physical condition of the solid, causing it to become a liquid, and, lastly, it assumes the gaseous state, if the repulsive power of heat be sufficient (8). Solids expand less, and gases more in bulk than liquids for equal increments of temperature.

The following table shows the increase in length of bars of different substances in rising from the temperature of freezing to that of boiling water.

1000,000 in length of	glass-tube	becomes at 212°	1000,861
———	crown glass	———	1000,875
———	platinum	———	1000,856
———	steel	———	1001,189
———	bismuth	———	1001,392
———	gold	———	1001,400
———	copper	———	1001,712
———	silver	———	1001,890
———	zinc	———	1002,942

By multiplying the linear increase of bodies by 3, the total increment in bulk is obtained with sufficient accuracy.

775. By the same elevation of temperature from 32° to 212°, the increase in bulk of the following fluids has been ascertained.

1000 parts of water		become	1046
———	alcohol	———	1110
———	fixed oil	———	1080
———	ether	———	1070
———	oil of turpentine	———	1070
———	mercury	———	1018 (De Luc.)
———	mercury	———	1020 (Dalton.)

Gaseous bodies expand equally for equal increments of temperature, 1000 parts of air at 32° becoming increased to 1375, at 212°, and the same amount of dilatation in bulk is experienced by other aëriform bodies.

The ratio of the expansion of gases has been lately corrected by Rudberg, and, according to his researches, one volume of gas at 32°, becomes 1·365 at 212°, so that a gas dilates $\frac{1}{493}$ of its bulk at 32° for each degree of Fahrenheit's thermometer (665), instead of $\frac{1}{480}$ as generally stated. If the volume of a gas at zero be 1, its bulk at any higher temperature may be readily found by the following formula:

$$\text{Volume } 1 + \frac{\text{Temperature by Fahrenheit's thermometer.}}{461}$$

For if the expansion be expressed in parts of the bulk at 0°, instead of 32°, the expansion is $\frac{1}{461}$ for each additional degree of temperature.

776. Perhaps the only real exception to the general law of bodies dilating by heat, and contracting in proportion as they are cooled, occurs in the case of water. If this fluid be heated to its boiling point, it will expand like other liquids, and if then it be allowed to cool, it will be found to contract in bulk steadily until it attains the temperature of 40° F., at which point it will attain its maximum of density. On continuing to diminish its temperature, the water will commence dilating in bulk until it attains the freezing point, or 32° F., and if it be cooled below this point without freezing, by avoiding all agitation, it will still continue to expand. The bulk of an equal weight of water at 48° and 32° is the same. The specific gravity of ice as compared with that of water at a mean temperature is as 0·94 to 1·0. In the act of freezing, a more marked amount of dilatation occurs; the bursting of water-pipes in winter from this cause is a phenomenon familiar to every one. An iron plug, weighing three pounds, was used to close a bomb-shell filled with water, and on freezing the latter, the plug was projected with violence to the distance of 415 feet.

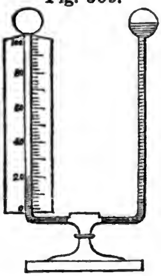
777. The great importance of water being the exception to the general law of bodies contracting by cold, may be illustrated by a reference to what would occur if this were not the case. For each winter the surface of our rivers and lakes becoming covered with a crust of ice, this would sink to the bottom, the fresh surface of water thus exposed would in its turn freeze, and another layer of ice would sink. This might go on even during a comparatively mild winter, until our rivers could thus easily be converted into a solid mass of ice, which no succeeding summer's sun could melt, and thus the whole earth would become a frozen mass, and all animated beings perish. But by the ordinances of Infinite Wisdom, it has been ordained that water should expand instead of contracting below the temperature of 40°, and the sheet of ice once formed being lighter than the adjacent water, floats on its surface instead of sinking, and thus helps to protect the fluids below it from the further influence of cold.

Fig. 358.

778. Before proceeding in his researches on the properties of heat, it is necessary for the inquirer to be furnished with some means of acquiring a measure of its intensity. This important intention is fulfilled by instruments termed thermometers, or measurers of heat; all depending for their action upon the expansion of bodies by heat. The first of these instruments was contrived by Sanctorius, an Italian physician in the 16th century, and is now known as the air-thermometer, because the indications it affords depends upon the expansion of included air. It consists of a glass tube, having a bulb blown at one end; the tube is then filled as far as the bulb with a colored fluid, and inverted in a vessel containing a similar liquid. The bulb is thus full of air, and on approaching a heated body towards it, the included air expands and depresses the fluid in the tube, a graduated scale attached to which marks the amount of subsidence of the fluid, and consequently of the expansion of air in the tube. These instruments are very delicate in their indications, but are rarely used, in consequence of their inability to measure any considerable range of temperature.

779. The air-thermometer was greatly improved by Sir John Leslie, whose differential thermometer (as it is termed) has been of essential service in elucidating many of the more obscure properties of heat. This instrument consists of a tube bent twice at right angles, each end terminating in a bulb. Before hermetically closing the bulbs, the tube is filled with sulphuric acid tinted with carmine or indigo, so that both bulbs are left full of air and the bent tube full of colored fluid. This instrument does not indicate any changes of temperature in the surrounding air, because so long as the air in both bulbs is equally heated the fluid will stand in the same level in the tube. If, however, a heated body, as the hand, be approached towards one bulb, the included air will expand and depress the fluid in the tube, driving it into the other bulb. The amount of depression of the fluid in the tube is measured as usual, by means of a graduated scale attached to one arm of the instrument. This very elegant piece of apparatus is termed the differential thermometer, because it indicates the difference of temperature in the air included in the two bulbs.

Fig. 359.

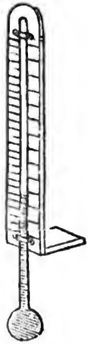


780. The expansion of liquids has been long used to indicate differences of temperature, and instruments thus constructed have the advantage of being steady in their indications, and of being capable of measuring considerable ranges of temperature. The two fluids now generally used for liquid thermometers are alcohol and mercury; the former is of most service in the measurement of very low temperature, whilst the ease with which it enters into ebullition, renders it unfit for the examination of temperatures near its boiling point. Whatever fluid is used in their construction, these instruments are always similarly formed, consisting merely of a tube of fine bore terminating at one extremity in a bulb, and filled with mercury, or alcohol at a boiling temperature to ensure the expulsion of air. The tube is fixed to a piece of hard wood, metal, or ivory, on which a scale is engraved. The lower end of this usually moves on a hinge so as to allow the ready immersion of the tube in any liquid.

781. To enable the indications of different thermometers to be comparable

with each other, some fixed points from which the graduation of the scale could be made is absolutely necessary. The fixed points are formed at the temperature in which ice melts and water boils, under a barometric pressure of 30 inches (185). The space between these points has been divided in an arbitrary manner, according to the views of different philosophers. Reaumur divided it into 80 equal parts or degrees, of which 0° corresponded to the temperature of melting ice (or freezing water) and 80° to that of boiling water. This graduation has been extensively employed on the continent. Celsius of Sweden divided the same space into 100 degrees, giving rise to the centigrade thermometer, in general use in France and Germany. The division of the thermometric scale employed in England is that of Fahrenheit, a German artist, who assumed for his zero the temperature produced by a mixture of ice and salt, and he divided the space between this and the temperature of boiling water into 212 degrees, of which the 32d corresponded to the temperature of freezing water, and to the 0° or zero of Reaumur's, and of the centigrade thermometer: the space between the temperature of boiling and freezing water is thus in the former divided into 80, in the latter into 100, and in Fahrenheit into 180 equal parts.

Fig. 360.



782. Much confusion has resulted from the use of these different scales, and to avoid this as much as possible whenever a temperature is expressed, it is customary to indicate which graduation has been employed, by placing after it the letters R, C, F, respectively. It is, however, very easy to convert the indications afforded by one kind of thermometer into another, by remembering the ratio borne by the degree of one to that of either of the other two. Thus, a degree of Fahrenheit's scale is equal to $\frac{4}{9}$ of one of Reaumur's and to $\frac{5}{9}$ of a centigrade degree. In practice, the following rules will be found useful for the conversion of the different thermometric degrees above freezing point, into each other.

A. *To convert a degree of Fahrenheit into its equivalent on Reaumur's scale.*

Multiply the number of degrees above or below 32° by 4, and divide by 9. Ex. What is 185° F. equivalent on Reaumur's scale.

$$(185-32 = 153) \times 4 = 612, \text{ and } 912 \div 9 = 68 \text{ R.}$$

B. *To convert a degree of Reaumur into its equivalent on Fahrenheit's scale.*

Multiply the degree by 9, divide by 4, and add 32. Ex. What is 16 R. equivalent to on Fahrenheit's scale.

$$(16 \times 9 = 144) \div 4 = 36, \text{ and } 36 + 32 = 68 \text{ F.}$$

C. *To convert a degree of Fahrenheit into its centigrade equivalent.*

Multiply the number of degrees above or below 32° by 5, and divide by 9. Thus, 212 F. are equal to 100 C.

F. $(212 - 32 = 180) \times 5 = 900$, and $900 \div 9 = 100$ C.

D. *To convert a centigrade degree into one of Fahrenheit.*

Multiply by 9, divide by 5, and add 32. Thus, 100 C. = 212 F.

C. $(100 \times 9 = 900) \div 5 = 180$, and $180 + 32 = 212$ F.

783. *Table for reducing the Centigrade to Fahrenheit's Degrees.*

Centigrade.	Fahrenheit.	Centigrade.	Fahrenheit.	Centigrade.	Fahrenheit.	Centigrade.	Fahrenheit.
100	212·	67	152·6	34	93·2	1	33·8
99	210·2	66	150·8	33	91·4	0	32·0
98	208·4	65	149·	32	89·6	— 1	30·2
97	206·6	64	147·2	31	87·8	— 2	28·4
96	204·8	63	145·4	30	86·0	— 3	26·6
95	203·	62	143·6	29	84·2	— 4	24·8
94	201·2	61	141·8	28	82·4	— 5	23·0
93	199·4	60	140·	27	80·6	— 6	21·2
92	197·6	59	138·2	26	78·8	— 7	19·4
91	195·8	58	136·4	25	77·0	— 8	17·6
90	194·	57	134·6	24	75·2	— 9	15·8
89	192·2	56	132·8	23	73·4	—10	14·0
88	190·4	55	131·0	22	71·6	—11	12·2
87	188·6	54	129·2	21	69·8	—12	10·4
86	186·8	53	127·4	20	68·0	—13	8·6
85	185·	52	125·6	19	66·2	—14	6·8
84	183·2	51	123·8	18	64·4	—15	5·0
83	181·4	50	122·0	17	62·6	—16	3·2
82	179·6	49	120·2	16	60·8	—17	1·4
81	177·8	48	118·4	15	59·0	—18	— 0·4
80	176·	47	116·6	14	57·2	—19	— 2·2
79	174·2	46	114·8	13	55·4	—20	— 4·0
78	172·4	45	113·0	12	53·6	—21	— 5·8
77	170·6	44	111·2	11	51·8	—22	— 7·6
76	168·8	43	109·4	10	50·0	—23	— 9·4
75	167·	42	107·6	9	48·2	—24	—11·2
74	165·2	41	105·8	8	46·4	—25	—13·0
73	163·4	40	104·0	7	44·6	—26	—14·8
72	161·6	39	102·2	6	42·8	—27	—16·6
71	159·8	38	100·4	5	41·0	—28	—18·4
70	158·	37	98·6	4	39·2	—29	—20·2
69	156·2	36	96·8	3	37·4	—30	—22·0
68	154·4	35	95·0	2	35·6	—31	—23·8

Fig. 361.

784. An ingenious form of thermometer founded upon the unequal expansion of two slips of metal soldered together by heat, has been occasionally employed. This form of thermometer has been greatly improved by M. Breguet of Paris. His instrument consists of a delicate ribbon of platina soldered to one of silver, by a very thin layer of gold. This compound bar is twisted into a spiral coil, one end of which is fixed to a support, the other carries a delicate gold needle as an index. As the two metals of which the coil is composed, expand very differently for equal increments of temperature, it follows that the helix of ribbon will uncoil, or become closer twisted, according to the temperature to which

it is subjected, the intensity of which will be indicated by the motion of the needle over a graduated arc.

785. For the purpose of measuring degrees of temperature higher than that of boiling water or mercury, instruments termed pyrometers have been employed. Of these the most celebrated was that contrived by Mr. Wedgewood; it consisted of a series of perfectly similar cylinders of baked clay, and a graduated scale to allow of their accurate measurement. One of these cylinders was then exposed to the temperature to be measured; in proportion as it became heated it contracted in bulk, and this contraction measured when the cylinder had cooled, became an indication of the temperature to which it had been subjected. In addition to other sources of error, the fact that pieces of clay would undergo the same amount of contraction by a moderate heat long continued, as by an exposure for a short time to an intense heat, becomes an insuperable objection to the indications of this instrument being depended upon.

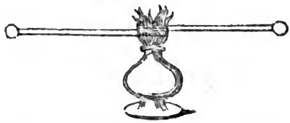
786. The most trustworthy pyrometer hitherto invented is undoubtedly that of Prof. Daniell. It consists essentially of a slender bar of platinum or hammered iron, whose linear expansion, when heated in a tube of black-lead, is measured by means of a little piece of porcelain resting upon the top of the bar, which in the act of expanding pushes it forward. When the apparatus has cooled, the displacement of the porcelain index becomes a measure of the expansion of the bar, and consequently of the temperature to which it has been exposed. The amount of displacement is measured by means of a delicately graduated scale furnished with a nonius.

787. From the researches of Dulong and Petit, it appears that the expansion of fluids, although regular up to 212°, increases in proportion as the heat rises above that temperature, as compared with the expansion of air. Hence the indications of an air and mercurial thermometer, although equal up to 212°, differ materially above that point; thus, the temperature of 586° on the mercurial would correspond to 572° on an air thermometer.

788. Every one is familiar with the fact that heat is conducted by different bodies with very different degrees of facility. Thus, a small piece of charcoal may be held by one end in the hand whilst the other is red-hot; and a piece of iron of the same size would, under similar circumstances, convey so much heat to the hand as to render holding it for any length of time absolutely painful. Among bodies of the same class, as metals, the same difference obtains: thus, a piece of platinum can easily be held in the hand whilst one end is red-hot; and a piece of copper similarly circumstanced will speedily burn the fingers.

Twist together one end of a piece of copper and platinum wire, each about six inches long. Place on each end a minute piece of phosphorus. Heat the point of junction with the flame of a spirit lamp, in a few seconds the phosphorus fixed to the copper wire will burst into flame, whilst that on the platinum will be unaffected.

Fig. 362.



789. The following general law of the propagation of heat by conduction has been determined: that if one end of a bar of metal be placed in connection with a source of heat, it will be found that for distances measured from this point in arithmetical progression, the excess of temperature above the surrounding medium will be in geometrical progression. MM. Dulong and Petit have also determined the law for the cooling of heated bodies, when they are placed in vacuo; in this case it is found that the rapidity of cooling

down to the temperature of the atmosphere decreases in geometrical, whilst the temperature diminishes in arithmetical proportion.

790. The conducting power of bodies for heat differs very considerably in different substances; and is generally materially diminished by breaking up solids into small portions; in this manner ignited coals can be easily carried in the hand if protected by a layer of cinders or ashes.

The conducting power of several substances is shown in the following table by Despretz, in which gold is taken as the standard.

Gold - - - -	1000
Silver - - - -	973
Copper - - - -	898
Platinum - - - -	381
Iron - - - -	374
Zinc - - - -	363
Tin - - - -	304
Lead - - - -	180
Marble - - - -	23·6
Procelain - - - -	12·2
Fine clay - - - -	11·4

791. Liquids conduct heat with great difficulty; on this account, if water be frozen at the bottom of a test tube and fresh water poured upon it, the latter may be made to boil by holding a spirit-lamp near the upper part of the tube, and yet the ice will remain unmelted. If, however, the heat be applied to the lower part of the tube, the ice will speedily melt, and the whole rapidly boil, not, however, from heat being conducted upwards, but from the ascent of heated particles of water from the bottom of the tube, on account of their being specifically lighter than the colder portion to which they thus communicate their heat (795), and thus the whole of the fluid becomes heated by the tendency to the production of an equilibrium of temperature between the particles.

Fig. 363.

792. Gases conduct heat even worse than liquids, a property frequently made use of to confine heat, as in the double door of furnaces, and in the double windows now so frequently used in houses; the layers of air confined between them proving the best possible barrier to the escape of heat from the apartment. It is on this account that the mere contact of very hot air can be endured by a person, whilst exposure to a fluid of the same temperature would produce intense pain. But if the heated air impinge upon the surface *as a current*, then its contact will be intolerable, in consequence of the repeated application of fresh portions to the surface. The same remark applies to intensely cold air; thus, in the Arctic regions men have been exposed to a degree of cold below that of freezing mercury without injury, so long as the air is calm, but upon the slightest wind occurring, the repeated contact of fresh portions of cold air will carry off so much heat as to freeze the extremities.

793. A practical application of the badly conducting power of air is found in the various articles of dress, which are generally warmer in proportion to the quantity of air entangled in the interstices of the material of which they are composed. Count Rumford suspended a thermometer in a glass tube, and prevented contact between it and the bulb of the thermometer by the interposition of the substance whose conducting power he wished to determine. The whole was first plunged into boiling water, and then removed into melting ice. The time required for the thermometer to cool from 190 F. to 54·5

was then noted in seconds, which thus became a comparative measure of the conducting power of the body. In this way he found that when air was alone interposed it required 576 seconds to cool down to 54·5. But when surrounded with

16 grains of	sewing silk, it required		817	seconds.
-	-	fine lint	-	- 1032
-	-	cotton	-	- 1046
-	-	wool	-	- 1118
-	-	raw silk	-	- 1284
-	-	beaver's fur	-	- 1296
-	-	eider down	-	- 1305
-	-	hare's fur	-	- 1315

We have a beautiful illustration of this property in the change of clothing of many animals, hair being in winter, and in the Arctic regions, replaced by wool, and feathers by down.

794. The fact with which every one is familiar, that a piece of iron or marble always feels colder than wood, flannel, or fur, similarly exposed, is explained by their different conducting powers. Thus, iron being a good conductor, rapidly attracts heat from the hand, and hence feels cold, whilst a piece of fur or woolen cloth, being a bad conductor, does not remove heat so rapidly, and thus feels comparatively warm. That the temperature of these bodies is really the same is proved by examining them with a thermometer; as all bodies exposed for a sufficient time to the same atmosphere rapidly acquire the same temperature.

795. As all bodies whose particles possess ready mobility on each other, as fluids or gases, are such bad conductors of heat; it is obvious that when heat is applied to one part of a vessel containing them, its communication to other portions of fluid must depend upon a process distinct from conduction. This has been illustrated by the case of fluid heated in a tube (792), when the diffusion of heat depends upon the ascent of heated particles, a process conveniently termed *convection.* When air is heated it ascends, because it becomes specifically lighter than the surrounding medium, and not in consequence of heat having a " tendency to ascend." This is the rationale of the balloon contrived by Montgolfier, which consisted of a large air-tight bag, having its open mouth downwards; beneath this a fire was maintained in the car, which, rarefying the air in the bag, rendered the whole specifically lighter than the surrounding medium, and it consequently ascended. The heated air at the equator thus ascends and travels towards the poles, whence an under-current of cold air passes to the tropical regions of the earth.

796. As heat is diffused through fluids by the process of convection, it follows that whatever diminishes, or interferes with, the motion of the molecules of fluid, will prevent the rapid communication of heat from one part of the liquid to the other. On this account viscid fluids, as water to which starch has been added, require a longer time to boil than pure water; and consequently a longer time to cool.

797. Bodies do not appear to have all the same capacity for heat, as, indeed, has been shown from the differences that exist in the rates of cooling of different substances (793); thus, water requires more than twice as much heat to raise it to a given temperature, as an equal weight of mercury; hence water is said to have a greater capacity for heat than mercury. All bodies thus possess a property denominated their *specific heat*, indicating the comparative amount of heat required to raise them to a given temperature.

798. If equal quantities of the same liquid at different temperatures are mixed, the temperature of the mixture will be the mean of the two. Thus

a pound of water at 60° mixed with the same quantity at 212°, will, when mixed, possess a temperature of 136°. But if equal weights of different fluids be mixed, the resulting temperature of the mixture will not be the mean of the two. A pound of mercury at 40°, mixed with the same quantity of water at 156°, will produce a temperature of 152·3°. Thus, whilst the temperature of the water is only depressed 3·7°, enough heat must have been evolved to raise the temperature of the fluid metal 112·3°. Then if the capacity of water for heat be assumed as the standard, that of mercury will be but 0·033 for 3·7 : 1123 :: 0·033 : 1. A bar of copper weighing a pound, if heated to the temperature of 300°, and immersed in a pound of water at 50°, will give up its excess of heat to the water, and both will acquire a temperature of 72°. The copper has consequently lost 228°, and the water gained 22°, and as 22 : 228 : : 1 : 0·096 = specific heat of copper. The specific heat of bodies may also be calculated by observing their comparative rates of cooling from a given temperature; or by observing how much ice is melted, or water heated by allowing the body to cool in a vessel surrounded by either of these bodies.

799. It is a curious fact, established by Dulong and Petit, that the specific capacity of bodies increases as their temperature rises, so that it requires less heat to raise a body of the temperature of 100° to 105°, than to raise one heated to 200° to 205°, although in either case but equal increments of temperature are indicated by the thermometer. Thus, the specific heat of water at 32° being termed 1·00, that of water at 212° will be 1·010°.

The following table gives the specific heat of several bodies, chiefly from the late accurate experiments of Regnault.

Water - - - - -	1·000
Alcohol - - - -	·660
Ether - - - -	·520
Nitric acid - - - -	·442
Sulphuric acid - - -	·333
Sulphur - - - -	·202
Phosphorus - - -	·188
Iron - - - -	·114
Nickel - - - -	·109
Cobalt - - - -	·107
Zinc - - - -	·095
Copper - - - -	·095
Silver - - - -	·057
Tin - - - -	·056
Platinum - - - -	·032

800 There exists, at least in numerous instances, a simple relation between the atomic weight of a body and its specific heat. Thus, if the number 3·1 be divided by the number expressing the specific heat of lead, tin, or zinc, the quotient in each case will very nearly represent the atomic weight of the body. In the same way the quotient from carbon will be double its atomic weight, and one-half their weight in the case of iodine, phosphorus, and silver. In compound bodies, although the number to be divided alters, yet a single ratio obtains; thus, in the case of the following carbonates the number is 10·4.

		$\frac{10 \cdot 4}{\text{Spec. heat.}}$	True atomic weight.
Carbonate lime . .	0.2044	50.9	50·6
- - iron . .	0.1819	57·2	58·1
- - zinc . .	0.1712	60.7	62·4

801. The specific heat of gases has been very carefully examined by different philosophers. The process generally pursued has been to heat the gas to a given point, and observe how much it raised the temperature of water through which a current was led by means of a spiral tube. Another mode has been contrived by Dr. Apjohn, and consists in vaporizing water by a current of the heated gases, when the latter will be cooled with a rapidity inversely proportional to their specific heats. Still, so much discrepancy exists in the results of different experimenters, that the subject must be regarded as open to further examination.

	Specific heat according to		
	Apjohn.	Delaroche.	Dulong.
Atmospheric air . .	1·000	1·000	1·000
Nitrogen	1·048	1·006	1·000
Oxygen	1·808	0·976	1·006
Hydrogen	1·459	0·900	1·300
Carbonic acid . . .	1·195	1·258	1·172
——— oxide . .	0·996	1·034	1·000
Nitrous oxide . . .	1·193	1·350	1·159

802. As the mixture of equal quantities of water at different temperatures possesses the comparative of the mean (798), it follows that when a pound of water at 32° is mixed with a pound at 172°, the mixture ought to be of the temperature of 104°, and experiment proves that such is the case. But if a pound of ice or snow at 32° be added to the same quantity of water of 172°, the mixture will be found to possess a temperature of only 32°. It is, therefore, obvious that some law must exist regulating this apparent loss of 140 degrees of heat, differing from that of specific capacity already explained. The heat that has disappeared must have been absorbed by the ice in passing from the solid to the liquid state, yet without increasing its thermometric heat; hence the 140 degrees of heat must have become concealed or latent in the water, which might thus be called a compound of true water and caloric or heat.

803. If a vessel of water be exposed to a freezing temperature, a thermometer immersed in it will gradually fall to 32°; if the water begins to solidify, the thermometer will indicate no further depression of temperature until the whole quantity is converted into ice, yet it must, during the entire process, be evolving that latent heat which, when in the form of water, preserved it in the liquid state. If, then, the ice be placed in warm water, it

will absorb heat from it, causing it to become latent, thereby assuming the form of water, whilst, as before shown (802), the temperature of the resulting mixture will not exceed 32°, the original temperature of the ice. These discoveries we owe to the researches of Dr. Black.

804. The comparative quantity of heat rendered latent during the liquefaction of bodies has not been very accurately determined for more than a few. The following table shows the results of some experiments on the latent heat of some substances. The first column of figures shows the interval of temperature through which the body, when liquid, would be heated by the amount of heat absorbed in the act of melting. The second column shows the degree of temperature which that amount of heat would communicate to a certain quantity of water:

Latent heat.

Water	140°	140°
Sulphur	143·7	27·14
Zinc	494·0	48·3
Bismuth	550·0	23·25

805. The remarkable absorption of heat produced by the liquefaction of solids, enables us to produce extreme degrees of cold at pleasure. Thus, if a quantity of nitrate of potass be stirred into a quantity of water, it produces an intense degree of cold in consequence of its absorbing a large amount of heat, which becomes latent in the solution. A mixture of snow and common salt rapidly liquefies, and absorbs as much heat during the process as to furnish us with a very available mode of producing low temperatures. If chloride of calcium be substituted for the salt, so great a depression of temperature is produced that mercury may thus be readily reduced to the solid state.

806. The evolution of latent heat in a sensible form occurs whenever a fluid becomes solidified. This may be shown by pouring a boiling saturated solution of sulphate of soda into a flask, and securing the mouth by tying over it a fold of moistened bladder. When cold, the solution will retain its liquid state without presenting any appearance of crystallization, until a hole is made in the bladder, when in an instant crystals will begin to shoot, the fluid will become nearly solid, and so much of the latent heat will be evolved that the vessel will feel sensibly hot to the hand.

807. Whenever fluids assume the gaseous state, an analogous conversion of sensible into latent heat occurs. Thus, if water be exposed to heat in an open vessel, it will on attaining 212° boil, and evolve considerable volumes of a gaseous vapor or steam, but during the whole time the ebullition continues, although receiving fresh heat every instant, neither the temperature of the water nor of the steam will ever exceed 212°. The enormous quantity of heat thus absorbed by the steam and becoming latent in it, may be rendered sensible by causing it to traverse a curved tube immersed in cold water. The steam in condensing will give up its latent heat to the water as sensible heat, and its increase of temperature will become an index of the quantity of heat latent in steam.

808. If steam be conducted for a certain time into eight ounces of water until its temperatere is raised from 60° to 188°, and the whole when measured be found to be nine ounces, it is obvious that the latent heat of the vapor of an ounce of water has been able to raise the temperature of eight ounces from 60° to 188°, or 128°. But as there were eight ounces, the whole heat when contained in the vapor of one ounce was equal to $123 \times 8 = 1024°$. This must not be regarded as all latent heat; for the steam while condensing should have formed water of 212°, whilst the temperature of the whole was

only 188°; hence, as 212 — 188 = 24, we must, to get the true proportion, deduct this from 1024, and 1024 — 24 = 1000, which is assumed as the measure of the latent heat of steam. It is the enormous quantity of heat thus latent in, or combined with steam, that renders it so important as a heating agent. One gallon of water converted into steam will contain sufficient heat to raise 5½ gallons from 32° to 212°. No other vapor, even presuming they were as readily procured as steam, would be so efficient as heating agents, in consequence of their containing a smaller quantity of combined or latent heat. The following table contains the numbers representing the latent heat of a few vapors:

Vapor of water	1000·
" " alcohol	457·
" " ether	312·9
" " oil of turpentine	183·8
" " nitric acid	550·

809. The expansion in bulk of fluids on assuming the state of vapor, generally decreases with the latent heat of the latter. Thus, a cubic inch of water is converted nearly into a cubic foot of steam.

1 cubic foot of	water becomes	1689·	cubic feet of vapor.
" " "	alcohol	493·5	" " "
" " "	ether	212·18	" " "

810. The temperature at which fluid bodies assume the form of solids, differs materially in different substances; this temperature is known as the congealing point of the body, and for the following bodies varies as is shown in the subjoined table.

Ether	— 46° F.
Mercury	— 39
Water	+ 32
Olive oil	36
Acetic acid	50
Wax	149
Sulphur	218

811. The temperature of the ebullition of fluids is subjected to great changes, according to the pressure to which they are subjected, and is not a fixed point like that of congelation. Fluids enter into ebullition much more rapidly if the pressures to which they are subjected are diminished. The following table contains the boiling points of a few liquids at a mean barometric pressure (185) of 30 inches.

Ether	100° F.
Alcohol	173·5
Nitric acid	210·
Water	212·
Sulphuric acid	600·
Mercury	655·

The material of which the evaporating vessel is composed, makes a marked difference in the boiling point of many fluids, especially if they are capable of forcibly adhering to its surface; thus, water will boil at 212° in a metallic, and at 214° in a porcelain vessel.

812. There is a very remarkable fact connected with the evaporation of fluids which has attracted much attention. If a few drops of water are

allowed to fall into a metallic cup, as a platinum crucible heated above the boiling point of water, the rapidity of evaporation will decrease with the increase of temperature of the vessel above 212°. If the crucible be red-hot, and the drops of water be watched, they will be observed to assume the form of sphericles rolling about the vessel, and on the temperature of the latter falling, they will be suddenly dissipated with a sort of explosion. The cause of this curious phenomenon seems to be that at an elevated temperature repulsion occurs between the vessel and the water, by which the drops of the latter are made to assume a spherical form, and do not come in contact with the vessel, being separated from it by a film of perfectly dry steam. As the temperature lowers, this repulsion lessens, and, at a certain point, the water loses its spherical state, comes in contact with the vessel, and is instantly dissipated. It is remarkable that water in this spherical condition has a temperature of about seven degrees below the boiling point, although actually rolling over a red-hot surface.

813. Ether is capable of assuming a similar spherical state, and is thus actually repelled by a red hot metallic surface. Iodine, when thrown on an ignited platinum crucible, melts, and forms a spheroidal mass like a black fluid, rolling over the surface of the vessel, and giving off but a very small quantity of vapor. In this state the liquid iodine does not come in actual contact with the platinum. On allowing the crucible to cool, contact occurs, and a sudden evolution of iodine vapor occurs.

814. M. Boutigny, to whom we are indebted for these curious facts, succeeded in freezing water in a red-hot crucible, by availing himself of this spheroidal state. He made a platinum crucible nearly red-hot, and poured into it anhydrous sulphurous acid, and afterwards an equal bulk of water. The rapid evaporation of the acid caused the conversion of the water into a mass of ice, which could then be removed from the still ignited crucible. Dr. Faraday placed in an ignited crucible solid carbonic acid and ether, afterwards pouring in mercury; the latter was frozen in the red-hot vessel. In both these experiments a thin layer of badly conducting vapor kept the freezing bodies from contact with the red-hot crucibles.

815. If all atmospheric pressure be removed, water will begin to boil at a temperature approaching that of melting ice. On this property, the elegant mode of freezing water by its own evaporation contrived by Sir John Leslie depends. Let a porous, earthen, shallow vessel be filled with water, and suspended over a saucer filled with sulphuric acid, under the receiver of an air-pump. On exhausting the air, a portion of the water robs the other of its heat to become converted into vapor, which is instantly absorbed by the acid. Fresh evaporation then goes on, and at last all the heat contained in the water above 32 is removed, and the portion left in the porous vessel is converted into ice. As the only use of the acid is to remove the vapor as soon as evolved, and thus restore the vacuum, any porous body capable of absorbing water, as fresh dried oatmeal, &c., may on the large scale be substituted for it.

816. Water may be readily frozen in the air-pump vacuum, by the evaporation of ether. Let a test-tube be partly filled with ether and immersed in a much wider one, the interspaces being filled up with water. On exhausting the air, the ether will rapidly boil and rob the water of its heat so rapidly, that in a few minutes the tubes will be found to be tightly frozen together. In an ordinary air-pump vacuum—

Ether will boil at	38° F.
Alcohol	49
Water	88

Conversely, by increasing the pressure to which fluids are subjected, their boiling points are raised. Of this, the well-known Papin's digester affords an example: in this contrivance water is submitted to heat in an air-tight vessel; it thus becomes exposed to the influence of an increasing pressure of its own vapor, and its boiling point becomes raised.

817. As might be expected from the dependence of the point of ebullition upon barometric pressure, it has been found that fluids boil at a lower temperature in elevated portions than at the level of the sea. Thus, Saussure found that on the summit of Mont Blanc, water boiled at 187° F. It has, indeed, been proposed to measure the elevation of mountains by ascertaining the temperature at which water boiled on their summits, and an instrument was contrived for the purpose by Archdeacon Wollaston. It has been found that the boiling point of water falls 1° F. for every ascent of 530 feet, equal to a difference of 0·589 inches in barometric pressure.

818. The production of ice by the evaporation of water (815), is well shown in an elegant contrivance of Dr. Wollaston, which he termed the cryophorus or frost-bearer: it consists of a tube bent twice at right angles, and furnished with a bulb at each end. Enough water to half fill one of the bulbs is introduced, and after being made to boil violently for a few minutes, the apparatus is hermetically sealed. Thus, it contains a quantity of water confined in vacuo, or rather in an atmosphere of aqueous vapor. If the empty bulb be placed in a freezing mixture, the vapor will be condensed, and a vacuum being thus restored, part of the water in the other bulb will be evaporated, and will distil into the cooled bulb, leaving the rest of the water converted into ice.

Fig. 364.

819. Although at ordinary pressures water boils at 212°, yet slow evaporation will go on from its surface at any temperature, even below freezing point. The vapor thus evolved mixes with, and is, as it were, dissolved by the air, which consequently is never absolutely dry, but always contains a certain portion of aqueous vapor. If an excess of aqueous vapor be evolved and mixed with the air, the latter will hold in solution, or at least in a state of intimate mixture, a quantity varying with the temperature. The warmer the air, the greater, *cæteris paribus*, the proportion of watery vapor it can hold in solution.

820. When the air is saturated with moisture, the elasticity of the watery vapor is at a maximum for a given temperature. The figures in the following table express the elasticity of watery vapor at different temperatures, in fractions of inches of mercury it is capable of supporting.

Table of Elastic Force of Gaseous vapor at different Temperatures. (*Dalton.*)

Temp.	Force of vapor.	Temp.	Force of vapor.	Temp.	Force of vapor.	Temp.	Force of vapor.
32°	0·200	49	0·363	66	0·635	83	1·10
33	0·207	50	0·378	67	0·655	84	1·14
34	0·214	51	0·388	68	0·676	85	1·17
35	0·221	52	0·401	69	0·698	86	1·21
36	0·229	53	0·415	70	0·721	87	1·24
37	0·237	54	0·429	71	0·745	88	1·28
38	0·245	55	0·443	72	0·770	89	1·32
39	0·254	56	0·458	73	0·796	90	1·36
40	0·263	57	0·474	74	0·823	91	1·40
41	0·273	58	0·490	75	0·851	92	1·44
42	0·283	59	0·507	76	0·880	93	1·48
43	0.294	60	0·524	77	0·910	94	1·53
44	0·305	61	0·542	78	0·940	95	1·58
45	0·316	62	0·560	79	0·971	96	1·63
46	0·328	63	0·578	80	1·00	97	1·68
47	0·339	64	0·597	81	1·04	98	1·74
48	0·351	65	0·616	82	1·07	99	1·80

821. It is often of importance to ascertain the quantity of watery vapor present in the air, and for this purpose various instruments termed hygrometers have been constructed. These instruments depend for their action either upon the expansion of some body capable of being readily affected by moisture, as hair, whalebone, catgut, &c.; or upon a thermometric arrangement by which the temperature at which the vapor begins to be separated from the air as dew, can be determined. Of these the first class are seldom worthy of confidence, as being incapable of affording correct results. The second class of instruments are now solely employed.

822. The simplest mode of determining the amount of watery vapor in the air is to carefully cool (by dropping ether upon the lower part of it), the bulb of a good thermometer, and watching the instant that a ring of dew appears upon its upper part. The temperature as indicated by the thermometer should be then carefully noticed, as it constitutes what is termed the *dew-point*, or the temperature at which the atmosphere would be saturated by the quantity of watery vapor present in the air at the time of the observation. By reference to tables given in works on meteorology, the mere knowledge of the dew-point, enables us to ascertain the absolute quantity of moisture present in the air, and resolve many other questions connected with the state of the watery vapor in the atmosphere.

823. The elegant hydrometer of Prof. Daniell, constructed on this principle enables us to observe the dew-point with greater facility than any other thermometric arrangement; although with care, it may with tolerable accuracy be determined by a sensible thermometer in the manner above described. As an example; the thermometer being at 78°, it is found, by cooling the bulb, that a ring of dew is deposited when the mercury falls to 40°. On referring to the last table, we find the elasticity of the vapor of water at that temperature is capable of supporting the pressure of 0 263 inches of mercury, and the

degree of dryness may be expressed in thermotic degrees as 38°, for 78° — 40 = 38. A more accurate mode of expressing the moisture of the air is by assuming as a standard of 1000, the point of saturation of the air at that temperature of the air. Thus, in the last example, the proportion of moisture in the air is to the quantity present if saturated, as 280 is to 1000; for

Elasticity of vapor at 78° Elasticity at 40°
0·940 : 0·263 : : 1000 : 280.

824. Another form of hygrometer is founded upon the fact of evaporation taking place with greater rapidity in dry than in moist air. This is known as the "wet-bulb hygrometer," and consists of two delicate mercurial thermometers placed side by side, the bulb of one being covered with a piece of white silk. The coated bulb is kept constantly wet by allowing water to drop slowly upon it, whilst the other is dry.* The evaporation of water from the wet bulb produces a depression in the column of mercury in the thermometer, and when this has attained its maximum, the degree at which the mercury stands in both thermometers should be noticed. The elasticity of the vapor at the dew-point is thus calculated by the following formula of Dr. Apjohn:

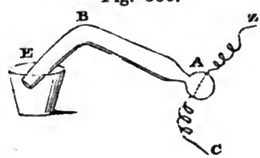
$$f'' = f' - \frac{d}{88} \times \frac{p}{30}$$

In this formula, f'' denotes the elasticity of watery vapor at the dew-point.
f' = elasticity of vapor at the temperature of the air (700).
d = depression of mercury in the wet-bulb thermometer.
88 = a co-efficient dependent upon the specific heat of the air and the latent heat of vapor.
p = the pressure of the air at the time of the observation as shown by a barometer.
30 = mean barometric pressure.

825. The chemical agency of heat is of the highest importance, as without its aid a very large proportion of the results of modern chemical investigations must have been for ever concealed from us: the student will find this matter treated of in all works on chemistry. But there is a peculiar action of heat which has not yet been sufficiently investigated, connected with its power of producing chemical decomposition; one result of this action will occupy our attention in another place (chap. xxx.)

826. Mr. Grove has, in a late very important contribution to the Royal Society, shown that at a considerable elevation of temperature, the compound gases or vapors are resolved into their constituents, as if the repulsive power of heat had been sufficient, not only to separate molecule from molecule, but even to rend their constituents from each other. He found that an intensely ignited piece of platinum, iridium, or silica, plunged into water, decomposed the evolved steam into oxygen and hydrogen. The best mode of showing this beautiful fact is by bending a tube into the shape ABE having a platinum wire, ZC, soldered with its bulb. The whole is filled with water and allowed to rest in a vessel of water. On connecting ZC with a battery of two nitric acid

Fig. 365.



* To the elaborate little work of Mr. Glaisher, of the Royal Observatory, on the Dry and Wet-bulb Thermometers, I would refer the student for every possible information connected with this subject.

cells (409), the water in the bulb will soon boil; it will become filled with steam, and the wire traversing it becoming red-hot, will decompose the steam into oxygen and hydrogen, minute bubbles of which will rise through the water.

CHAPTER XXIX.

THERMOTICS.

RADIANT HEAT.

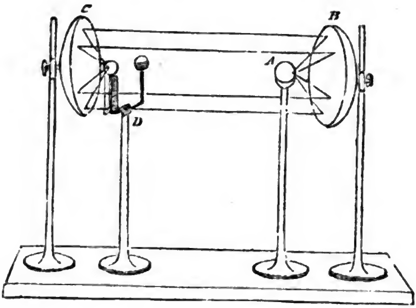
Radiant heat, 827. *Reflected to a focus*, 829. *Proportion reflected by different bodies*, 831. *Law of diminution*, 832. *Seat of radiation*, 833. *Leslie's experiments*, 834. *Connection of cooling and radiating powers*, 835. *Absorption*, 836. *Terrestrial heat*, 838. *Dew and hoarfrost*, 839. *Möser's figures*, 840. *Thermography*, 841. *Diathermancy*, 844. *Thermo-multiplier*, 845. *Table of diathermanous bodies*, 846. *Properties of rock-salt*, 847. *Effects of screens*, 848. *Refraction of heat through lenses*, 849—*through prisms*, 850. *Refrangibility of heat*, 851. *Separation of light and heat*, 852. *Polarization of heat*,—*by tourmalines*, 853—*by mica*, 854. *Preparation of mica plates*, 855. *Polarization by refraction and reflection*, 856. *Depolarization of heat*, 857. *Circular polarization*, 859—*by refraction*, 860—*by internal reflection*, 861.

827. In the preceding chapter, the general properties of heat, in combination with matter, or rather of heated bodies, have been discussed. We have now to regard this agent as independent of ponderable matter, moving through space like light, and when unaccompanied by the latter, invisibly.

828. Every one, when standing near a fire, must be aware that he feels a sensation of warmth, and consequently, that if actual heat does not pass from the fire to him, that some cause, perhaps some undulating motion, must emanate from it, and which, on reaching his surface, excites the sensation of heat. In the following account of the properties of radiant heat, it must be recollected that the latter word is generally used to express the effects of those undulating movements of ether which excite the sensation of heat, and not as referring to any form of matter. In this view, also, a ray of heat must have a definition analogous to that already given of a ray of light (562). When a heated body is exposed in the air, or in a vacuum, it continues to evolve rays of heat, until it attains the temperature of the surrounding medium. These rays pass off in straight lines, and obey the law of reflection precisely like light (566).

829. If a heated body, as a red hot iron ball A (fig. 366), be placed in the focus of a concave metallic mirror B, its radiant heat will pass from it to the mirror, and be reflected from it in parallel rays (572). These, if collected by a second mirror C, placed ten or twelve feet from the first, can be easily brought to a focus, and the bulb of a delicate thermometer D placed near the latter, will be immediately acted upon by the reflected heat, the fluid falling in the tube. In this manner phosphorus or gunpowder may be easily inflamed at a considerable distance from the source of heat, by concentrating the calorific rays, by means of a metallic concave mirror.

Fig. 366.



830. If a mass of ice be substituted for the hot ball, the thermometer in the focus of the second mirror will indicate a depression of temperature. This has been erroneously assumed as an illustration of the reflection of cold rays, which in fact have no existence; cold being merely the diminution or absence of heat. In this arrangement of the experiment, the ball of the thermometer being warmer than the ice, plays the same part as the red-hot iron did (829); it gives up its heat, which is reflected by the mirror in whose focus it is placed, and reaching the ice, becomes latent (802), in its assisting to convert it into fluid water.

831. Reflection of heat takes place from the surface of bodies, and, in general, the more highly polished these are, the more readily do they reflect light. If 100 rays of heat be incident, at an angle of 60° from the perpendicular, on reflecting surfaces of the following bodies, the proportion of heat reflected will be represented by the figures in the subjoined table.

Polished gold	76
——— silver	62
——— brass	62
Unpolished brass	52
Polished brass varnished	41
Glass plate blackened at the back	12
Looking-glass	20
Metal plate blackened	6

832. If heat undergoes reflection *immediately* from the surface of good reflectors, it scarcely seems to be affected by the space it may happen to traverse, except in being slightly diminished in quantity by the absorbing power of the medium through which it passes. If, however, heat be communicated to a body, and radiate from its surface, it then, if examined at different distances from the radiant body, will be found to decrease as the squares of the distance, like light.

833. Radiation, or the power of throwing off the heat communicated to a body, does not take place absolutely from the surface, but at a minute distance beneath it. On this account the state of the surface of the radiating body materially affects its radiant power, probably from its interfering with, or facilitating the escape of heat from a point immediately beneath it. The general laws of calorific radiation have been most amply investigated by Sir John

Leslie, and we are indebted to him for most of the knowledge we possess on this subject.

834. The radiant power of bodies is conveniently examined by replacing the hot ball in the focus of one of the concave mirrors (829) by a cubic canister of tin filled with hot water. The angles of this canister should be provided with grooves, so that plates of the body whose radiant powers are under examination can be slipped in. Or the sides may be painted with different substances, as lamp-black, white lead, &c., if the radiant powers of such bodies are to be determined. In every case, that side of the canister which is covered with the body to be examined, must be turned towards the surface of the mirror in whose focus it is placed. The indications of the thermometer placed in the focus of the second mirror, become a measure of the radiant power of the substance under examination. The radiating power of lamp-black is the most considerable of all bodies, and is assumed as the standard of comparison with others in the following table:

Lamp-black	100
Writing-paper	98
Crown-glass	90
Ice	85
Red lead	80
Plumbago	75
Tarnished lead	45
Clean lead	19
Polished iron	15
Other bright metals	12

As a general rule, for the same substances, the radiating power is diminished by even slightly compressing their surfaces, as by polishing, and in the case of metals is increased by tarnishing or oxidation.

835. The rapidity of cooling of bodies depends greatly upon the radiating power of the substances of which they are composed. Leslie filled a polished tin globular vessel with hot water; it cooled down to a certain temperature, as indicated by a thermometer, in 156 minutes. On repeating the experiment after covering the vessel with a thin layer of lamp-black, it cooled down to the same point in 81 minutes. Thus the rapidity of cooling was nearly doubled by increasing the radiating power of the surface of the vessel. Count Rumford allowed hot water to cool in two polished brass cylinders, leaving one naked, and covering the other with a fold of linen. In the former the water cooled 10 degrees in 55 minutes, whilst in the latter it lost the same amount of heat in 36½ minutes. The good radiating surface of the linen thus accelerated the loss of heat. For a similar reason, vegetable infusions, as tea, are best prepared in bright metallic vessels, as an earthen or black tea-pot radiates a large amount of heat. In heating rooms with tubes of hot-air or steam, their surfaces should be roughened or blackened, to facilitate the radiation of heat into the apartment; whilst that portion of the pipe employed to convey the source of heat into the room should be kept bright or polished, to prevent unnecessary loss by radiation.

836. Bodies which possess a high radiating power, also, in general, are endowed with another property no less important, that of *absorbing* heat; and, as a general rule, whilst the best radiators are the worst reflectors, they are the best absorbers. When a body has thus absorbed heat, it again diffuses it by a secondary radiation. In the experiment of the two mirrors (829) it is found that the metallic plates of which they are composed do not become sensibly heated by the rays from the red-hot ball impinging upon them. But if their reflecting concave surfaces were covered with lamp-black, the mirror

nearest to the ball would become hot from the absorption of heat, and scarcely any would reach the second mirror. The blackened surface would, however, continue to radiate the heat acquired from the ball until its temperature is reduced to that of the atmosphere.

837. The color of a body appears to exert a considerable influence on its absorbing power, and the darker the tint the more readily does the body absorb heat. This is familiarly illustrated by Dr. Franklin's experiment of placing on the surface of snow several pieces of cloth of different colors. On examining them in a short time after, the snow will be found to have melted in very different proportions under the pieces of cloth, having melted in the greatest quantity under the darkest pieces, as shown by their having sunk to the greatest depths.

838. The solid mass of our earth owes its warmth to what is termed *terrestrial heat*, for which it is not indebted to the sun's rays, but to some internal cause. So far as researches have extended, it appears probable that the temperature of the earth increases one degree (Fahrenheit) for every 60 or 70 feet we descend beneath its surface, so that at a depth of a few miles the mass of the earth must be actually red-hot. A large proportion of the terrestrial heat is radiated into space, and hence the temperature of the air decreases as we ascend to any elevation; this diminution of heat is also one degree for every 290 feet above the level of the sea. From repeated observations it appears that the mean or average temperature of any place corresponds to the heat of the earth examined 30 feet below its surface. The lines connecting all the places on the surface of the globe possessing the same temperature are called *isothermal lines*. Such lines are not parallel to the equator as they ought to be if the temperature of the earth alone depended on solar radiation, but they really form a series of irregular curves, which in Europe incline most to the north.

839. During the night the temperature of the air is always many degrees colder than in the day. The earth, therefore, radiates into space a portion of the heat it had absorbed in the day-time. Thus becoming cooled, a deposition of the aqueous vapor of the air takes place upon its surface, and is familiarly known by the name of *dew*. This, in cold weather, freezes in the act of being deposited, and constitutes *hoar frost*, which is the ice of dew. The greatest quantity of dew is always found deposited on that portion of any surface which radiates best; hence a meadow will often be found covered, whilst the smooth road by its side is nearly free, in consequence of grass radiating freely. If a polished plate of metal be exposed at night by the side of a piece of woolen cloth, the latter will, in the morning, be found covered with dew, whilst the badly radiating metal will be free. Deposition of dew may be readily prevented by opposing any obstacle to free radiation; every gardener is aware that he can prevent the deposition of dew over a portion of ground, by merely supporting over it, by means of slips of wood, a thin cloth or handkerchief, which prevents the free radiation of heat from the surface thus protected. The demonstration of the real source of dew and hoar-frost we owe to the researches of Dr. Wells.

840. The connection of the state of surface with a tendency to the deposition of vapor is well shown in the curious phenomena discovered by Prof. Möser, and known as Möser's figures. To observe these, place a coin upon the surface of a piece of looking-glass, or of common glass, having the back covered with tin-foil, and allow a few sparks to fall upon the coin from the prime conductor of an electrical machine. Quickly remove the coin, and gently breathe over the surface of the glass, when the outline of the impression on the coin will become beautifully defined upon the glass in drops of watery vapor. If a series of plates are super-posed, and the coin placed upon the upper one, and sparks allowed to fall upon it, the upper surface of each plate

will present similar phenomena when breathed upon. These figures may be rendered visible, by exposure to the vapor of iodine or mercury, quite as well as by breathing upon them. Similar effects have been shown, by Mr. Hunt, to result when a coin, gently heated, is allowed to rest on a plate of polished silver: on removing it and breathing on the plate, or exposing it to the vapor of mercury, the figure of the coin will be rendered beautifully visible. If a shilling be allowed to rest on a looking-glass for some time in the sun, and be then removed, a tolerably distinct outline of the coin will appear on gently breathing on the glass.

841. The condition of surface of body on which the vapor is deposited (840) is owing to the radiation of heat from the coin or other body placed on it. Founded on these curious states we have the art of Thermography, to which attention has been especially directed by Mr. Hunt. He found that to obtain a good image, the superposed body must be composed of a different material from the plate on which it is placed. Thus, when a sovereign, a shilling, and a penny, are placed on a polished copper-plate, the latter gently warmed by passing the flame of a spirit-lamp under it, then allowed to cool and the coins removed, beautiful pictures of the sovereign and shilling appear on exposing the plate to the vapor of mercury, whilst a scarcely visible image of the penny will be obtained.

842. Pieces of blue, red, and orange-colored glass, of white, crown, and flint-glass, mica, and paper, were placed on a plate of polished copper, and allowed to remain in close contact for half-an-hour. On removing them, and exposing the plate to the vapor of mercury, distinct images of the red, orange, flint, crown-glass, and paper were obtained, whilst the blue glass and mica had scarcely made any impression.

843. A plate of copper is amalgamated so as to present a brilliant reflecting surface by rubbing it with nitrate of mercury, a sheet of printed paper is placed on it with the letters downwards, and pressed in close contact by several folds of paper pressed by a weight. The whole should be allowed to rest on a warm surface. In half an hour the radiation of heat from the black letters will have produced a marked although as yet invisible effect on the surface. To render this obvious, the plate should be exposed to the vapor of mercury, which will adhere to those parts which corresponded to the white portion of the printed paper. It should next be exposed to the vapor of iodine, which will blacken the parts to which the mercurial vapor has not adhered, and a beautiful copy of the printed page will result.

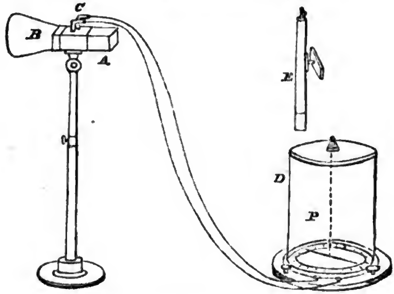
844. Radiant heat becomes absorbed in part in traversing the most transparent media; it is supposed that the heat of the sun loses one-fifth of its intensity in traversing a column of air 6000 feet in length. It must not be, however, supposed, that those media which are the most transparent with regard to light, possess the same property with regard to heat. Indeed, it has been satisfactorily proved, that a piece of smoke-quartz, so thick as to intercept the passage of a considerable portion of light through it, yet allows the passage of rays of heat which are entirely checked by even thin plates of absolutely transparent alum or citric acid. Media which allow of the free passage of heat, are termed *diathermanous*, and those which have not this power are said to be *athermanous;* the term diathermanous being to heat what diaphanous is with regard to light.

845. Heat, like light, is not only absorbed by certain media, but admits of single and double refraction, plane and circular polarization,—properties for the discovery of which science is almost exclusively indebted to the labors of M. Macedoine Melloni, and of Professor Forbes of Edinburgh: the latter philosopher is the discoverer of the plane and circular polarization of heat. The application of a delicate thermo-electric battery (519), in which an elec-

tric current capable of being measured when circulating through the coil of a well-constructed multiplier (468, 514), is excited by very minute alterations of temperature, has been the main source of these curious discoveries, by enabling the philosopher to detect changes of temperature otherwise utterly inappreciable. The most complete apparatus of this kind is that used by Prof. Forbes (fig. 367).

The thermo-electric battery consists of about 36 delicate bars of bismuth

Fig. 367.



and antimony, alternately connected at their extremities, and separated laterally by folds of paper or other non-conductor; the whole is packed in the case A, and supported by a stand, so as to be movable in any direction. The bent wires C are connected with the terminal elements of the little battery, and connection is thus readily made with a delicate multiplier D, whose indications are examined through a telescope E, so that in this manner deviations of the needles to the extent of a fraction of a degree are easily observed. The battery is so minute, that the section of A presents an area of only 0.4 inch. The rays of heat are frequently concentrated on the thermo-electric apparatus by means of a conical metal reflector B, and so delicate is this apparatus, to which the term thermo-multiplier is conveniently applied, that the mere approach of the hand towards the mouth of B, will excite a current capable of deviating the needle from its position through several degrees. When observations are made with this instrument, it is usual to interpose a screen of wood or pasteboard between the source of heat and the mouth of B, or extremity of the battery, if the reflector is not used, and to remove it at the instant all is arranged for observation.

846. Diathermanous bodies differ much, not only in their power of transmitting radiant heat, but also in their facility of allowing heat from different sources to permeate them. In general, heat accompanied by light is capable of penetrating most diathermanous media, whilst the rays of *dark heat*, as those emanating from a metal heated below redness, or from boiling water, are checked by many very transparent bodies. Solar heat again readily passes through glass, whilst the luminous heat of a bright fire is almost completely imperceptible by a plate-glass screen. The following table presents the results of Melloni's experiments on the power of plates of the following bodies 0·103 inch in thickness to transmit heat.

Name.	Rays transmitted from 100 issuing from the following sources of heat.			
	Oil lamp.	Red-hot platinum.	Copper at 732°	Copper at 212°
Rock salt	92	92	92	92
Fluoride calcium	78	69	42	33
Iceland spar	39	28	6	0
Plate-glass	39	24	6	0
Borax	18	12	8	0
Citric acid	11	2	0	0
Alum	9	2	0	0
Sugar-candy	8	0	0	0
Ice	6	0	0	0

847. Of the nine substances in the above table, five are permeable by dark and luminous heat, but in very different proportions; the other four are diathermanous to luminous heat alone. Of all bodies hitherto discovered, rock-salt transmits most of the incident rays of heat, hence it must be regarded as the *true glass* of radiant heat. The oil-lamp used in these experiments is a very steadily-burning one, with a square neck (Locatelli's). The incandescent platinum consisted of a coil of wire of that metal ignited in the flame of a spirit-lamp, and the copper used as the other sources of heat was blackened.

848. After the calorific rays have traversed a diathermanous body, they appear to have undergone some physical change, for if again allowed to fall upon a second plate of the same body, a much larger proportion of them traverse it. It thus would appear, that in the act of passing through a medium, the rays are divided into two unequal portions, one of which is absorbed and the other transmitted; and thus, *sifted* from the readily absorbable rays, the transmitted ones are better able to traverse a second portion of the same medium. From the last table we learn that but 9 per cent. of rays emanating from an oil-lamp are transmitted by a plate of alum, but if these transmitted rays be allowed to fall upon a second plate of this substance, 90 per cent. will permeate it, and consequently but 10, instead of 91 per cent., be absorbed. On the other hand, Melloni found that a slice of a green tourmaline transmitted 18 per cent. of the calorific rays incident upon it, whilst it allowed but 1 per cent. of heat which has passed through alum to traverse it, thus intercepting 99 per cent. The same slice of tourmaline, although thus nearly impervious to heat *sifted* through alum, yet freely transmitted 30 per cent. of the rays which had previously passed through black glass. The cause of these physical changes is found in the unequal refrangibility of calorific rays (851).

849. Calorific rays are capable of refraction through prisms and lenses like light. In experiments of this kind, however, the reflecting medium must be composed of a substance capable of readily transmitting heat; and for this purpose rock-salt is almost the only substance that can be employed, the extraordinary facility with which it transmits more than 90 per cent. of incident heat, rendering it to the latter what glass is to light.

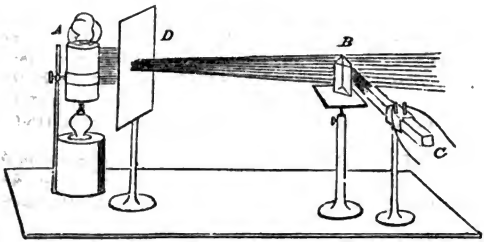
If a convex lens be made of transparent rock-salt, it will with facility bring radiant heat, of even low intensity, to a focus. The heat from a vessel of boiling water can thus be brought to a focus by a salt lens, with as much facility as luminous rays are by a lens of glass (593). The superior intensity

of the calorific rays in the solar beams allows them to pass through ordinary convex lenses of glass, and the common burning-glass affords an instance of solar heat being brought to a focus with the light.

850. If heat be incident in a rock-salt prism, it is like light resolved into a series of rays of unequal refrangibility (606), and an invisible calorific spectrum is the result. The dispersion of the rays of heat is, however, much less than that of light under similar circumstances.

The refraction through a prism may be readily shown by the following arrangement, in which the calorific rays, emanating from a vessel of boiling water A, after passing through an opening in a screen D, are incident on a rock-salt prism B. These undergo refraction, which is detected by the thermo-multiplier C; the incident rays being bent in their course by the action of the prism.

Fig. 368.



851. When calorific rays emanating from different sources are incident on the prism in this apparatus, it is found that the angle of their incidence must be changed by moving the source of heat to get the maximum action on the galvanometer; or, what comes to the same thing, the position of the latter must be slightly altered. The explanation of this is readily found in the unequal refrangibility of rays of heat. Thus Melloni found that the heat from incandescent platinum was refracted more than that from a hot plate of black copper.

852. Admitting the existence of rays of heat of unequal refrangibility, we have a key to the phenomena before alluded to in the physical alteration produced in heat after traversing screens of different bodies (848). Thus, rock-salt allows rays of all refrangibilities to pass in equal proportions, a plate of alum intercepts all, save the least refrangible rays, and, as might be expected when these rays are thus *sifted* from the others, they can with greater facility traverse a second plate. Melloni covered a plate of rock-salt with soot, and found that only rays of the highest refrangibility could pass, becoming to heat, what violet-colored glass is to light, and by combining with this a plate of alum, which refuses to transmit any but the less refrangible rays, all heat was absolutely stopped, the combination becoming absolutely athermanous or opaque to heat. When a plate of alum is combined with one of green glass, the brilliant light of a lamp, or even of the sun, is readily transmitted, but their heat is absolutely stopped. An experiment which shows very satisfactorily the independence of light and heat.

853. Rays of heat are capable of being polarized by processes analogous to those in which this physical change is produced in light (660). These phenomena were first discovered by Prof. Forbes.

If a ray of heat be refracted through a very thin plate of brown tourmaline, it emerges partly polarized in one plane, the polarization being never so complete as when light is similarly treated. If the emergent ray be incident upon a second similar plate, it will be partly absorbed, and the rest transmitted or dispersed, according to the position of the axis or the section of tourmaline. When the axes of the two plates are parallel, a considerable portion of the heat passes the second plate, and may be measured by the thermo-multiplier. But if the axis of the second plate be at right angles to that of the first, the great majority of this heat will be stopped, and not reach the multiplier. By comparing the quantity of heat which reaches the multiplier when the axes of the plates are parallel as compared with that which reaches it when they are crossed, the proportion of heat polarized by the first tourmaline may be ascertained. If one hundred rays from incandescent platinum reach the multiplier, when the axes of the tourmaline are parallel, 76 only pass when the axes are crossed, hence 24 are polarized.

854. The most satisfactory evidence of polarization is obtained when plates of mica are used instead of tourmaline. These should be split extremely thin, and a film should be ignited for some time in a clear fire. By the action of heat, the film becomes split into innumerable laminæ, and then is capable of exerting an exceedingly powerful polarizing power on heat and light. These ignited films need never be more than $\frac{1}{1000}$ inch in thickness, and should be placed in wooden or pasteboard tubes to allow of readily manipulating with them.

855. The film of mica thus prepared should be placed either in the wooden tube, or on soles of thin wood, so that the rays of heat may be incident upon them at an angle of about 34° to their surface. When heat is incident upon

Fig. 369.

one film placed as shown at A in the direction C, a large proportion of it emerges polarized, and this will be either transmitted or checked by a second inclined plate according to its position. It will be transmitted if the plates are parallel, as at fig. 1, and checked if they are crossed as in fig. 2, just as would happen to light under similar circumstances. In this manner the following proportions of radiant heat from different sources may be polarized:

Argand lamp - - - -	82 per cent.
Incandescent platinum - - -	79
Brass heated to 700° - - -	68
The heat from ditto transmitted through glass	73
Boiling water - - - - -	49

856. Prof. Forbes succeeded in polarizing heat by refraction through thin inclined plates of rock-salt, just as light is by glass plates (675); when heat was incident at 55° to the surface, he found that with three-plates one-seventh, and with six one-half, of the incident rays were polarized.

When plates of split mica were arranged so as to reflect incident heat at an angle of 56° to the perpendicular, heat was polarized in the following proportion:

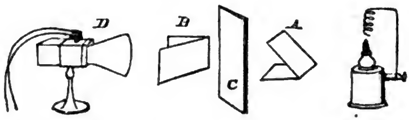
From incandescent platinum - -	65 per cent.
Brass at 700° - - -	61
Argand lamp - - - -	55

These last results are explained by the angle of incidence probably approaching nearer to the polarizing angle for heat radiating from red-hot platinum than to that of heat from the two other sources, as Professor Forbes has succeeded in proving that heat of different refrangibilities is unequally polarizable.

857. We have learnt that polarized light is prevented reaching the eye by crossing the tourmalines (668); and, if reflecting plates are employed, by placing the planes of reflection and polarization at right angles to each other (670). If a thin plate of mica or selenite be placed between the polarizing and analyzing plates, it causes the polarized ray to undergo a physical change, termed *depolarization* (685), by which its plane of polarization is altered, and it is enabled to undergo reflection and transmission, producing a brilliant display of complementary colors. Precisely analogous phenomena occur in the case of polarized heat, and are readily detected by the thermo-multiplier, as, of course, no *visible* effects occur, as in the case of light.

858. The depolarizing effects of a thin film of mica are best observed, on account of the great diathermancy of this substance. For this purpose, let the heat radiating from any source, as a coil of platinum wire ignited by the flame of a spirit-lamp S, be polarized by refraction, through the inclined film

Fig. 370.



of mica A, in the manner before explained (855). These rays will be partly intercepted by the second mica plate B, so that but 21 per cent. will reach the thermo-multiplier (D). Having observed the effect on the galvanometer, produced by these transmitted rays, place between A and B, a film of mica C, and if the neutral axis (685) of the film be inclined to the plane of polarization of the rays of heat, an increased effect will be observed on the multiplier. This arises from the plane of polarization of the heat refracted through A, being altered by the doubly refracting film of mica C, and thus a portion of the heat previously checked by B, becomes enabled to traverse it. In four experiments, Professor Forbes found that the proportion of heat thus depolarized, when the neutral axis of the film was inclined 45° to the plane of polarization, compared with that which reached the thermo-multiplier when it corresponded to that plane, was as

126 : 100 120 : 100 120 : 100 113 : 100

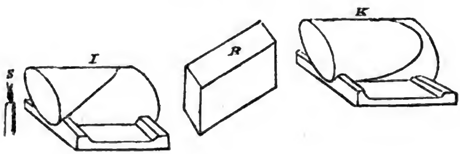
When the principal section of the mica C corresponded to the plane of polarization, no depolarizing effect was exerted, precisely as in the case of light (685).

859. The circular polarization of heat has been effected in two modes,—by refraction through an exceedingly thin film of mica, and by internal reflection through a piece of rock-salt cut in the shape of Fresnel's rhomb (713). A test of the circular polarization of light is found in the fact that if, whilst the polarizing plates A and B (855) are crossed, so that a minimum of heat reaches the thermo-multiplier, a body be interposed between them, if capable of converting the rectilinear into circular heat, will produce such a physical change in the calorific rays passing through B, that no great difference of effect shall be shown by the multiplier, in whatever position the analyzing plate is placed.

860. A film of mica, which in ordinary polarized light appeared of the pale reddish-white color of the first order of Newton's rings (643), and which so far interfered with the undulations of plane polarized light as to *nearly* convert it into circular light, was first employed. When introduced between the two sets of mica plates A and B (858), this film produced such a physical change in the heat, as to cause it to reach the thermo-multiplier in nearly equal proportions, whether the polarizing and analyzing plates were parallel or crossed. When incandescent platinum was employed as the source of heat, the quantity of circularly polarized light which thus passed the analyzing plate under the influence of the mica film, amounted to 40 per cent. of the whole quantity which would have passed if A and B (858) were parallel, and the film absent.

861. A very elegant mode of causing plane polarized heat to acquire similar physical properties was contrived by Professor Forbes in imitating of Fresnel's mode of obtaining circular light by internal reflection (713). For this purpose, he procured a rhomb of rock-salt having two angles of 45°, and of sufficient length to allow of the emergence of a ray after two internal reflections. The

Fig. 371.



most convenient arrangement for the experiment is shown in the figure, where S is the source of heat, I and K are respectively the polarizing and analyzing mica plates (855) placed in tubes of wood, and R is the rhomb of salt. It was found that when the plane of reflection in R corresponded, or was perpendicular, to the plane of polarization of the ray, it underwent no change and either emerged from, or was stopped by K, according to its position. But when the plane of internal reflection was inclined 45° to that of polarization, it emerged from R, circularly polarized, and nearly an equal proportion of it passed through K, in whatever angle its plates formed with the primitive plane of the ray.

CHAPTER XXX.

PHOTOGRAPHY.

Action of light on silver salts, 862—*Colors developed by*, 864. *Effects of the spectrum*, 865. *Copying engravings by photographic paper*, 866. *Photographic camera*, 868. *Daguerreotype*, 869. *Preparation of sensitive paper from salts of silver*, 871—874. *Action of spectrum on*, 875. *Process for fixing*, 876. *Cyano-argentotype*, 877. *Positive paper*, 879. *Excitation of latent pictures*, 880. *Calotype*, 881. *Mr. Brooke's paper*, 882. *Ferrotype*, 883. *Cyanotype*, 884. *Chromotype*, 886. *Anthotype*, 887. *Parathermic rays*, 888.

862. The chemical influence exerted by the solar rays upon salts of silver have been already referred to (626). These phenomena have been within the last few years made the subject of careful study, and with so much success that a property long supposed to be peculiar to a few argentine combinations has been shown to be of a much more general character. The labors of Sir John Herschel have been among the most interesting and important in this inquiry, and this great philosopher has shown that there scarcely exists a combination, whether of organic or mineral origin, whose molecular constitution is not more or less affected by the solar rays. The study of these extraordinary effects constitutes the science of *Photography.*

863. If a piece of paper be moistened with a solution of common salt, and then dipped in one of nitrate of silver, a thin covering of chloride of silver is formed on its surface, and it is left in a state extremely sensitive to the action of light. If a piece of such paper be exposed to the sun's rays, or to the diffused light of day, it becomes darkened in color, and assumes a brown, bluish, or black hue, according to the length of exposure, or to the proportion of silver present. The chemical change thus experienced by the chloride of silver is not yet satisfactorily understood; it, however, appears probable that a partial conversion into oxide occurs. It is certain that some important molecular change does take place; for if a piece of paper thus blackened by exposure to light, be digested in a solution of hyposulphite of soda, (in which chloride of silver is readily soluble,) it gives up but a small proportion of the silver, all the chloride which has become changed by the action of the sun's rays being insoluble in the solution of the hyposulphite.

864. When a slip of paper thus prepared is exposed to the solar spectrum (605), it becomes most darkened in the violet ray and in the space beyond it occupied by the lavender band of Sir John Herschel (610). In the position of the more refrangible rays, the paper is scarcely affected except that occasionally it is observed to assume a very faint tint, bearing some resemblance in hue to the colored bands of the spectrum, which thus, within certain limits, imprint their own tints upon the paper. The following table shows the results of an experiment in which the paper was rendered sensitive with chloride of silver:

Colored band of spectrum.	Tint impressed on the paper.
Red - - - -	None
Orange - - - -	Faint brick red
Orange-yellow - -	Brick red
Yellow - - - -	Red passing into green

Colored band of spectrum.	Tint impressed on the paper.
Yellowish-green - -	Dull bottle-green
Green - - - -	Ditto passing into bluish
Bluish-green - - -	Sombre blue
Blue - - - -	Black passing into metallic yellow
Violet - - - -	Ditto
Beyond violet (lavender)	Violet or purplish black.

865. The opposite extremities of the solar spectrum appear to exert very different effects on the prepared paper (863), appearing to neutralize within certain limits each other's effects. Thus, a piece of the paper blackened by violet light is bleached by exposure to the red ray. Sir John Herschel found that when a violet and red ray were allowed to fall simultaneously on a piece of the paper impregnated with chloride of silver, they nearly neutralized each other's effects. If the changes which are thus produced in the chloride of silver in common with other compounds, are effected by means of *chemical rays* in the spectrum, we may explain this neutralizing effect to the interference of the undulations producing them.

866. As the darkening of the chloride of silver is confined to those portions which are exposed to light, it is easy to apply this property to the copying of patterns of lace, leaves, engravings, &c. For this purpose, a piece of paper properly prepared (871—886), should be placed upon a smooth surface, and upon it the lace, or leaf, should be laid; a plate of glass should then be placed on the whole, and pressed down with a moderate weight. By a short exposure to the sun, or a longer one to diffused day-light, all that part of the paper uncovered, by the lace, &c., will be darkened in color or even blackened; the rest being protected from the action of light, retaining its primitive whiteness. On removing the paper, an exact copy of the object placed upon it will be found. This drawing will, however, soon vanish by the blackening of the whole impression, unless it is *fixed* by the removal of the unchanged chloride from the paper. For this purpose, after soaking for a few seconds in water, the paper should be sponged over with a solution of hypo-sulphite of soda, which, by dissolving the unchanged chloride, fixes the drawing (876). A solution of common salt may be used for fixing, but its action is far inferior to that of the hyposulphite. Washing with a solution of ferrocyanide or iodide of potassium will also partially fix the picture.

867. In copying an engraving or ink-drawing, it is obvious that the paper on which it is printed must not be so thick as to interfere with the action of light. It should be placed, face downwards, on a piece of sensitive paper, and kept as close as possible by means of a plate of glass pressed down by means of screws or weights. After exposure to direct sunshine for a sufficient time, the paper should be removed, and the picture fixed by one of the processes last described.

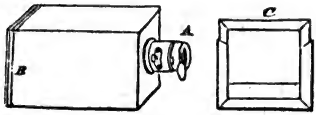
868. The greatest triumph of the photographic art is undoubtedly the success it has arrived at, in rendering permanent the beautiful but fleeting images of a camera-obscura. The credit of having first obtained these wonderful results, belongs in this country to Mr. F. Talbot, and in France to MM. Niepce and Daguerre, whose processes are, however, perfectly distinct from each other.

The camera (737) used in these experiments should be provided with a good *achromatic* (628), or at least a *meniscus* (590) lens, of about ten inches focus, and capable of adjustment by means of a sliding tube at A. The other end of the box should be provided with grooves, so as to admit a wooden frame C; or a pane of ground glass at will. In either case these must so fit the grooves as to prevent the admission of extraneous light.

To use this instrument, the end B should be closed by means of the plate

of ground glass, for the purpose of receiving the images produced by the lens. On placing the camera opposite the landscape or object to be copied,

Fig. 372.



its image will be visible on the ground glass, and the lens should be adjusted until it becomes as perfect and well-defined as possible.

To copy the images of the camera, a piece of paper rendered as sensitive as possible by some one of the processes described in this chapter, should be fixed in the frame, and covered with a wooden slide, so as to protect it from light. The whole should then be introduced into the camera in the groove from which the ground glass had been previously removed. The wooden slide being then withdrawn, the images will be formed on the sensitive paper, and there leave a permanent impression. The time required for the completion of this process will vary with the sensitiveness of the paper from a few seconds to half an hour. The pictures thus obtained must be fixed by means of some of the processes described in this chapter.

869. The discovery of M. Daguerre undoubtedly constitutes the most wonderful in the science. The exquisite beauty of the *Daguerreotype* pictures, no less than their remarkable sharpness of outline, has always arrested the attention of observers. The general details of the process are the following:

A plate of copper is covered on one side with a thin sheet of silver, and as perfect a polish and smooth a surface as possible must be given to the latter, by the use of dilute nitric acid, and friction with fine tripoli and oil, until it presents that blackish lustre so peculiar to highly polished silver, when viewed at a certain angle. The silver surface is then rendered sensitive by being exposed to the vapor of iodine, which is best effected by placing at the bottom of a wooden box a piece of thin deal, saturated with a solution of iodine in alcohol, and resting the plate with the silver face downwards, on two little projecting ledges in the interior of the box, so that it must be a couple of inches above the iodized wood. In this manner a delicate yellow coating of iodide of silver is formed over the plate: this is extremely sensitive to light, and therefore must not be exposed to its influence until placed in the camera. The surface may be rendered still more sensitive by suspending it for a short time over an aqueous solution of bromine, by which the yellow color of the iodized plate is converted into a pale rose-red. These operations should be, like all preparatory photographic processes, performed in a dark room by the faint light of a taper. The camera obscura being adjusted to the object, the prepared plate should be slipped into the groove made to receive it, care being taken not to expose it to light during its transit from the room where the last operation was performed.

In the course of a few seconds the full effect is generally obtained, and the camera with the plate should be removed to a dark room. The plate being then removed, will appear to have undergone no visible change, the picture being present, but latent. To render it visible, the plate is suspended in a dark box over a capsule of mercury, gently heated by a spirit-lamp. The ledges which support the plate should be so placed that the latter may rest at an angle of 45 degrees to the side of the box. The mercury will slowly

rise in vapor, and will adhere in the form of extremely minute gray globules to those parts of the plate where the light has fallen, leaving the parts corresponding to the shadows of the picture untouched. In this way the picture may be seen gradually unfolding itself, and this beautiful part of the process may be watched by the light of a taper through a little window in the box. As soon as the picture has obtained its maximum of distinctness, the plate must be removed, and being placed in a vessel, should be covered with a weak solution of hyposulphate of soda to dissolve all the bromo-iodide of silver left unaltered by light. After washing with water, the plates may be allowed to dry, and the picture is left *fixed* from all further action of light.

870. The rationale of this curious process consists in exposing a highly sensitive surface of iodide or bromo-iodide of silver to light, by which some molecular change is effected in the parts on which the light has acted, by which the vapor of mercury becomes condensed upon those portions to the exclusion of the others. The darks and shadows of the Daguerreotype pictures are formed by the naked surface of the silver shining with its full "black" lustre, whilst the lights are formed by the gray globules of mercury. Hence the slightest touch with the finger is sufficient to rub off some of those adhering globules, and thus to spoil the picture. The state of surface produced by the light, by which the vapor of mercury is enabled to adhere to particular portions only, is, perhaps, analogous to that which induces the formations of Möser's figures with vapor of water (840).

871. In giving a brief sketch of the different modes which have been employed to render paper and other bodies sensitive to the action of the chemical rays of the spectrum (626) as they exist in ordinary light, it is important to distinguish between two classes; one including those which receive a direct and visible impression from an image thrown upon them; the other containing those which undergo a certain molecular change, but in which the picture is *latent* (880), and requires the application of some reagent to render it visible. Almost all metallic salts and vegetable pigments belong to one or other of these classes, some of the most remarkable of which will now engage our attention. The compounds of silver, including the different species of *argentotype*, are among the most sensitive, and these may be further distinguished into the *chloro-iodo-chromo-argentotype*, &c., each presenting several points of peculiar interest.

872. The *chloro-argentotype* has been already described (863), and with care may be prepared of sufficient delicacy to receive the impressions of the camera-obscura (868) after a few minutes' exposure. The following is one of the best modes of preparing an excellent paper of this kind.

Dissolve a quarter of an ounce of nitrate of silver in two ounces of distilled water, and forty grains of common salt in the same quantity of water.

Select some sheets of blue wove post-paper, and damp them by pressure between folds of wet bibulous paper. Then sponge them evenly with the solution of salt, and having drained them of superfluous moisture, let them become nearly dry. The solution of silver should then be applied evenly over the surface (which should be previously marked with a pencil to distinguish it) by means of a broad flat brush; the paper thus prepared should be dried in the dark, once more carefully brushed over with the solution of silver and again dried, and preserved for use between folds of dark paper.

873. *Iodo-argentotype* is exceedingly sensitive to light, and may be prepared by brushing over one surface of fine paper a solution of twenty grains of nitrate of silver in half an ounce of water, carefully drying it; and then applying a solution of ten grains of iodide of potassium in half an ounce of water. This paper is of a pale yellow color, and keeps tolerably well.

874. *Bromo argentotype* is, according to some, the most delicate of all, and is

prepared by brushing over paper a solution of 100 grains of nitrate of silver in an ounce of water, and when dry a solution of forty grains of bromide of potassium in an ounce of water, again drying it, and then applying one more wash of the silver solution. This very sensitive paper is very liable to blacken spontaneously in the dark.

875. It is remarkable that these three preparations, although closely resembling each other, are acted upon differently by the chemical rays of the spectrum (626). Thus, if slips of these different papers be exposed to the spectrum, the paper prepared with the chloride of silver will be most darkened in the blue ray, that with the iodide beyond the violet, and that with the bromide will be blackened for the whole length of the spectrum, but most intensely in the indigo ray.

876. The pictures impressed on these papers are best *fixed* in the following manner. Dip them in warm distilled water, and drain them in the dark on a napkin, then cover them with a thin layer of a saturated solution of hyposulphite of soda, and after soaking them for a few minutes, wash them with water (which in the case of the iodide and bromide should be warm) until the washings no longer taste sweet. It is remarkable that the pure chloride, iodide, and bromide of silver, are scarcely sensible to light, but instantly acquire this power by the addition of an excess of the nitrate.

877. Many other salts of silver may be employed with more or less success as photographic agents, their range of sensibility differing very remarkably. Among these compounds one produced by the action of the yellow prussiate of potass on iodide of silver, discovered by Mr. Hunt, is the most remarkable. This, the *cyano-argentotype*, is thus prepared, and is worthy of notice from its presenting a close approach to the beauty of the calotype pictures.

Glazed letter-paper is washed over on one side with a solution of two drachms of nitrate of silver in an ounce of distilled water, and quickly dried. It is then immersed for a minute in a weak solution of iodide of potassium, (1 drachm to 8 ounces water), removed, and gently washed with pure water, and, lastly, dried in the dark. The paper so far prepared may be kept for any length of time, and to render it highly sensitive, it is only necessary to brush it over with a solution of one part of yellow prussiate of potass in eight of water. These papers are only sensitive whilst wet, for if allowed to dry in the dark, they become nearly insensible to the influence of light; immediately, however, acquiring their susceptibility to light by merely moistening them with cold water. The pictures taken in the camera by this process are readily fixed, by being washed first with water and then with the solution of the iodide.

This kind of paper is blackened nearly equally by the whole prismatic spectrum.

878. In all these pictures the lights and shades are reversed, and we have what are called *negative* pictures. To prepare from these *positive* copies, in which the light and shades are correctly represented, all that is necessary is to place the well-fixed (876) photograph, with its face downwards, on a sheet of sensitive paper, press them close together by means of a plate of glass in a proper frame, and expose them to the direct rays of the sun. In a short time the picture will be impressed upon the paper, and may be fixed in the manner already described.

879. It is, however, possible to prepare a *positive paper*, or one which will at once give a picture with its lights and shades in a proper position. The following is the process contrived by Mr. Hunt for this purpose. Good letter-paper is soaked for a few minutes in a solution of forty grains of chloride of sodium in four ounces of water. It is then wiped, dried, pinned on a board, and brushed over with a soft sponge dipped in a filtered solution of nitrate of

silver 120 grains, water an ounce and a half, and alcohol half an ounce. The paper is then exposed to the sun, which darkens it immediately. The solution of silver is again to be applied and the paper once more exposed to the sun, until it assumes a uniform chocolate color. It is then to be dried in the dark. To use this paper it should be brushed over with a solution of thirty grains of iodide of potassium in an ounce of water. If this paper be placed whilst moist in the camera obscura, it will be impressed with a beautiful sæpia-colored positive picture in half an hour. These pictures are best fixed by washing them with water to remove the excess of iodide, but are unfortunately liable to fade.

880. If any of the sensitive papers (873, &c.) be exposed in the camera, &c. for too short a time, either no picture at all, or at least a barely visible one, will be noticed; still the absence of impression is no proof that a decided effect is not produced. This may indeed be demonstrated by the application of some reducing agent, as the gallic or succinic acids, proto-sulphate of iron, &c., which would not act upon the paper before exposure. We have, founded on these principles, some processes for preparing paper of wonderful sensibility; and of these the first which merits attention is the calotype of Mr. Talbot.

881. This extremely sensitive paper has been largely used for the purpose of taking portraits by means of the camera obscura. The process itself has been made the subject of a patent; its outlines are as follows:—

A sheet of fine post-paper is brushed over with a solution of 100 grains of nitrate of silver in six ounces of distilled water. It should then be cautiously dried at a distance from the fire, or by exposure in a dark room. When dry it is dipped into a solution of iodide of potassium, (500 grains to a pint of water,) dried between folds of bibulous paper, immersed for an instant in pure water, and gently washed with distilled water, and dried. A fine uniform coat of pale yellow iodide of silver is thus spread over the paper, which must be kept for use. To give the iodized paper its maximum of sensibility, it must be rapidly brushed over with equal parts of an acid solution of nitrate of silver, and a cold saturated solution of gallic acid; then immerse it for a moment in distilled water, and drain it on blotting-paper. The acid solution of silver is made by dissolving one hundred grains of crystalized nitrate of silver in two ounces of distilled water, and adding one-sixth of its volume of strong acetic acid. In this state it is remarkably sensitive, and when nearly dry may be exposed in the camera. But a short time, often a few seconds, is sufficient to obtain a beautiful picture. The paper should then be removed and the picture impressed upon it, although as yet invisible, must be "brought out" by again washing it with a mixed solution of silver and gallic acid, keeping the paper warm by placing it in a dish over boiling water. The beautiful picture thus procured may be fixed by washing with water and then with a solution of 100 grains of bromide of potassium in 10 ounces of water.

These pictures, which are among the most beautiful in the photographic art, are negative, and may be made to yield positive impressions by the processes already described (878).

882. A paper of exquisite sensibility has been contrived by Mr. Brooke, and employed by him to register the magnetic variations (271). This gentleman availed himself with great ingenuity of the different susceptibilities of the iodide and bromide of silver to the different rays (626) of the spectrum, and thus succeeded in preparing paper so sensible to the influence of light as to rival the more complex calotype. His process is the following: one surface of well glazed paper is sponged over with a solution of twelve grains of bromide of potassium, four of iodide of potassium, and four of isinglass, in an ounce of distilled water. Care must be taken to apply the solution equally

over the paper, which is then to be dried. When required for use, it is gently brushed over in the dark with a solution of fifty grains of nitrate of silver in an ounce of water; the only light used in this process must be that of a lamp covered with red glass. This paper should be used whilst damp. A minute or two is sufficient for its exposure in the camera; on removing it, a cold solution of gallic acid should be poured over it, and in a few seconds the picture will become visible. As soon as it is sharply defined, the process should be stopped by immersing the paper in warm water, and fixing it in the usual manner (876). I have seen Mr. Brooke obtain a sharp impression on this paper by allowing a pencil of light reflected through a narrow slit by a mirror from a small camphine lamp at the distance of several feet in fifteen seconds. I have, on a dull March morning, obtained a sharp picture in the camera in three minutes by the aid of this paper.

883. Many varieties of *ferrotype* have been described; these all are indebted for their susceptibility to light to per-salts of iron, which become wholly or partially reduced by the solar rays. The most convenient salt for this purpose is the ammonia-citrate. If paper be washed over with a solution of this salt in ten or eleven parts of water, and carefully dried in the dark, it is remarkably sensitive to light. If a piece of lace (for example) is pressed in close contact with a piece of the paper, and exposed for half-an-hour to the sun, a sharp and well-defined picture will be obtained. If, however, the sun's rays be not very bright or the exposure to their influence be much shorter, a scarcely visible impression will be formed. As, however, all the points exposed to the light have undergone a change, from the partial conversion of the sesqui-citrate into a proto-salt, on washing the paper with a solution of the red-prussiate of potass, (ferro sesqui-cyanide of potassium,) a pretty picture will appear of yellow lace on a blue ground, the prussiate acting only on the reduced portion of the iron-salt. In the same way a solution of nitrate of silver will produce a fawn colored picture on a blackish brown ground, and a neutral solution of chloride of gold will produce a picture with a splendid purple ground, the *chrysotype* of Sir John Herschel.

884. The class of *cyanotypes* are peculiarly beautiful, and some of them have peculiar claims to our attention. One of the best is made by washing paper with the red prussiate of potass, and when dry exposing it to the sun, with the object to be copied pressed in close contact with it by a plate of glass. The effect of the light is to evolve prussian blue, which remains fixed to the paper. On soaking the picture thus produced in water, the unchanged prussiate is removed, and a white picture on a beautiful blue ground results. This easily prepared paper affords a ready and excellent means for copying ferns, sea-weeds, lace-work, engravings, &c., but is not sufficiently delicate for the camera.

885. The most sensitive cyanotypes hitherto obtained are those prepared by the following processes, devised by Sir John Herschel.

Mix together equal parts of a cold saturated solution of bichloride of mercury with one of the ammonio-citrate of iron, (1 part of the citrate to 11 of water.) Before any precipitation occurs, wash over with this fluid a sheet of yellow wove post-paper, and dry it. Paper thus prepared may be kept for some time without becoming deteriorated. A piece of this should be placed in the camera, until a decided, although faint impression is just visible. It should then be removed and rapidly brushed over with a saturated solution of the yellow prussiate of potass, diluted with three times its bulk of strong gum-water. The picture gradually unfolds itself in an extremely beautiful manner, and should be allowed to dry in the dark, where it should remain for some days, when it will bear strong light with impunity. If a picture thus obtained be heated, it is converted from a blue positive, into a brown

negative one (888). By keeping, however, it recovers its positive character and original color.

886. The chromotype affords a sensitive paper of sufficient delicacy for copying lacework, ferns, &c., and may be made by simply washing thin paper with a solution of bichromate of potass, and drying it quickly before a fire. Let an object be placed on this paper, (which possesses a fine yellow color,) and having been secured by pressure with a plate of glass, be exposed to the direct rays of the sun, until the yellow color of the paper is changed to a rich brown. On removing the object, its outline will be found beautifully defined on the paper, the drawing being yellow on a brown ground. To secure this from further change, all that is necessary is to soak the paper in water, to remove the unchanged bichromate, by which process the picture is left nearly white on a brownish-yellow ground, and may be preserved for any time without further change. The rationale of this process is found in the reduction of a portion of the chromic acid to the state of oxide.

887. From the elaborate researches of Sir John Herschel, it has been proved that scarcely any colored fluid from the vegetable kingdom, or any compound which chemistry has made us acquainted with, exists, which is not more or less sensitive to the chemical influence of light. He succeeded in obtaining well-defined photographs, by merely using paper impregnated with the colored juices of flowers and other parts of vegetables; and to these the generic term of *antho-type* has been applied. For an account of these beautiful researches, I must beg to refer the reader to the published papers of Sir John.*

888. It is a remarkable fact, that all the photographic processes are considerably expedited by the application of a gentle heat. Sir John Herschel found that in many instances the photographic change produced by exposing a strip of prepared paper to the solar spectrum, the changes which would require a considerable time to be effected, were rapidly produced by holding behind the paper, whilst thus exposed, an iron heated below redness. In the account of the beautiful calotype process (881) of Mr. Talbot, it has been mentioned, the paper must be heated to bring out the picture properly. In the cyanotype picture (885) we have seen that an actual alteration of color, and the conversion of a positive into a negative picture, take place by the mere application of heat.

The agent in producing this curious change is considered by Sir John Herschel to consist of rays of some kind abounding in the red and orange bands of the solar spectrum, and emitted by bodies heated just below redness. These rays, for which the term of *para-thermic* has been proposed, appear to bear the same relation to the true calorific rays, as those active in producing chemical and photographic phenomena do to the chemical ones.

NOTE.

For further information on the interesting subjects of this chapter, I would refer the student to the papers of Sir John Herschel in the Philosophical Transactions, and the Researches on Light by Mr. Hunt, London, 1844, as also to sections VII. and VIII. of Müller's Physics.

* Philosophical Transactions.

ALPHABETICAL INDEX.

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THE END.

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